ECONOMIC ANALYSIS OF COSTS INCURRED FROM CHEMICAL EXPOSURES IN THE WORKPLACE RESULTING IN NON-CARCINOGENIC RESPONSES AS ADDITIONAL JUSTIFICATION FOR POLLUTION PREVENTION PROJECTS

THESIS

Michael [illegible] Forcht, Captain, USAF
Timothy L. Neu, GS-11, USAF

AFIT/GEE/ENV/93S-

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GEE/ENV/93S-6

ECONOMIC ANALYSIS OF COSTS INCURRED FROM CHEMICAL EXPOSURES IN THE WORKPLACE RESULTING IN NON-CARCINOGENIC RESPONSES AS ADDITIONAL JUSTIFICATION FOR POLLUTION PREVENTION PROJECTS

THESIS

Michael L. Forcht, Captain, USAF
Timothy D. Neu, GS-11, USAF

AFIT/GEE/ENV/93S-6

The views expressed in this thesis are those of the authors and do not reflect the offical policy or position of the Department of Defense or the U.S. Government.

AFIT/GEE/ENV/93S-6

ECONOMIC ANALYSIS OF COSTS INCURRED FROM CHEMICAL EXPOSURES IN THE WORKPLACE RESULTING IN NON-CARCINOGENIC RESPONSES AS ADDITIONAL JUSTIFICATION FOR POLLUTION PREVENTION PROJECTS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air Education and Training Command
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering
and Environmental Management

Michael L. Forcht, B.S.
Captain, USAF

Timothy D. Neu, B.S.
GS-11, USAF

September 1993

Approved for public release; distribution unlimited

Acknowledgements

This research required a great deal of support from a variety of individuals. Those deserving recognition for their contributions include, foremost, our research advisor, Capt Jim Aldrich, who encouraged both creative and critical thinking. Capt Aldrich's expertise in pollution prevention and economics really helped us develop our topic. We would also like to acknowledge our reader Lt Col Mike Shelley, whose extensive knowledge of the risk assessment process and toxicology added our efforts immeasurably. Lt Col Shelley offered some particularly useful insights and deserves additional recognition.

Several individuals assisted us in the gathering of necessary information and deserve our thanks. Mr Harold Ludwig, a member of the Document Development Branch at NIOSH, spent a lot of time answering questions and provided information needed to complete this effort. Capt Gary Meyer, for OEHL, deserves special recognition. He allowed us access to the Air Force database on workplace accidents, which was the basis for many of our conclusions.

Finally, we wish to especially thank our wives and families for their continual support and understanding. They endured many hardships during this thesis process but their support never wavered.

Table of Contents

Acknowledgements. ii

List of Figures vi

List of Tables. vii

Abstract. viii

I. Introduction 1

General Issue 1

The Current Situation 2
Air Force Pollution Prevention 2
Disposal Costs 2
The Problem 3
The Approach 4

Specific Problem 5

Research Objectives 5

Scope 5

II. Literature Review 7

Overview 7

Hazardous Materials 7
Ignitability 8
Corrosivity 8
Reactivity 8
Toxicity 9

The Pollution Prevention Program 10
History 12
EPA Policy 13
Air Force Policy 14
Leadership's View on Pollution Prevention 15
Benefits 16

Project Funding 17

Life-Cycle Costing 20

Total Cost Assessment 20

Risk Analysis 21
Hazard Identification. 22
Risk Assessment. 22

Source/Release Assessment 23
Exposure Assessment 23
Dose-Response Assessment 23
Risk Characterization 28
Risk Significance 29
Risk Communication 29

Workplace Exposures 29

Accidents 30

Conclusion 31

III. Chronic Noncarcinogenic Effects 33

Quantifying Exposure 33
Source/Release Determination 33
Exposure Determination 34
Dose-Response Determination 34
Risk Characterization 38
Multiple Exposures 39
Probability of Incidence Model 40
Cost Estimation 41

Model Application 42

IV. Acute Noncarcinogenic Effects 43

Quantifying Exposure 43

Accident Data 44
Chemical Selection 44
Accident Costs. 46
Data Analysis/Correlations 49

Military Data Source 49

Civilian Data Sources 52
The National Safety Council. 52
The Texas Institute for Advancement of Chemical Technology. 54
The National Institute for Occupational Safety and Health 55
Dichloromethane 56
Trichloroethylene. 56
Methyl Ethyl Ketone 56
Occupational Safety and Health Administration. . 57
Bureau of Labor and Statistics 58
Bureau of Workman's Compensation 58
Chlorine Compounds 58
Acetone and other Ketones 60

Conclusion 61
V. Conclusion 64
Overall 64
Chronic Exposures 64
Acute Exposures 65
Recommendations 66
Appendix A 67
Appendix B 72
Appendix C 73
Appendix D 76
Appendix E 85
Bibliography 89
Vitas 96

List of Figures

Figure		Page
1.	Waste Management Hierarchy	11
2.	Dose-Response Curve	24
3.	Measured Response Values	26
4.	LD_{50} and Dose-Response Curve	40
5.	Estimation of Probability	41

List of Tables

Table Page

1. Pollution Prevention Benefits 16
2. Environmental Compliance Project Priority Framework 18
3. RfC Adjustment factors 27
4. Chronic Hazard Index Estimate for Liver Lesions 39
5. Targeted Priority Chemicals for Hazardous Waste Reduction 44
6. OEHL Chemical Categories 50
7. Fatalities by Poisoning 52
8. Probability of Poisoning 53

Abstract

This research determines the applicability of using costs associated with chemical exposures in the workplace in the financial justification of pollution prevention projects. Specifically, this thesis looks at costs incurred due to the onset of noncarcinogenic effects caused by chemical exposures. Average costs are determined through researching applicable statistical cost data.

Acute effects are analyzed using an analysis of available statistical accident data from multiple sources. Expected values are then calculated based upon the projected cost of an accident and the probability of having an accident.

Chronic effects are analyzed using an empirical analysis. A risk assessment is used to determine the likelihood of developing a chronic response to workplace exposures measured in terms of a hazard quotient. A probability of developing a response and the cost is then multiplied by the hazard quotient to predict the cost associated with chronic effects due to workplace exposures.

This research shows that for the purposes of financially justifying pollution prevention projects, costs due to acute effects of chemical exposure are insignificant. Further, the cost due to chronic effects cannot be used at this time for pollution prevention justification because necessary workplace exposure data does not exist.

ECONOMIC ANALYSIS OF COSTS INCURRED FROM CHEMICAL EXPOSURES IN THE WORKPLACE RESULTING IN NONCARCINOGENIC RESPONSES AS ADDITIONAL JUSTIFICATION FOR POLLUTION PREVENTION PROJECTS

I. Introduction

General Issue

The Air Force, like any other organization, has budgetary constraints. Base Operations and Maintenance (O&M) budgets are continually depleted by increasing hazardous waste disposal and management costs. Because of these constraints, environmental projects are prioritized according to economic and other considerations to ensure the optimization of available funds. However, due to the difficulty in placing monetary values on intangibles such as risk reduction, environmental protection, and liability avoidance these issues are difficult to consider using current economic analysis (5:3).

To adequately determine project cost, the value of these additional issues must be determined. This thesis attempts to place a dollar value on one of these issues, risk reduction. This can assist managers in determining the additional cost savings realized through implementation of pollution prevention projects. The current situation, the problem, and the approach to solving the problem is outlined below.

The Current Situation. In response to growing public concern about environmental degradation, Congress passed the Pollution Prevention Act of 1990. The act establishes as "national policy" a hierarchy of pollution protection, which emphasizes source reduction and recycling (40:3). Under the Pollution Prevention Act, all generators of hazardous waste are required to establish a pollution prevention program to reduce or eliminate the generation of hazardous and non-hazardous wastes (7:197).

Air Force Pollution Prevention. Air Force Policy Directive 19-4 establishes the responsibilities and goals of the Air Force's pollution prevention program. Its primary objective is to reduce the use of hazardous materials and production of hazardous wastes by source reduction and recycling where applicable, which simply restates the Pollution Prevention Act's objectives. The concept is to address pollution before it is generated; to avoid costly cleanups and civil suits, to conserve raw materials, and to reduce disposal costs.

Disposal Costs. Once wastes are generated, industry and public agencies spend approximately $120 billion annually to treat or contain the wastes (4:5). The Air Force contribution to this expense was approximately $19 million in 1990 (63:1-1). To make matters worse, costs for hazardous waste treatment and disposal have increased by 300 percent over the past decade due to new regulations and amendments to new regulations (4:5). Adding to the increasing costs associated with the use of hazardous materials and waste handling, the Federal Facilities Compliance Act now makes government agencies subject to compliance fines and criminal and civil suits in cases of environmental misconduct.

The Problem. Pollution prevention is the best means to comply with future environmental regulations, yet project funding is a problem. Currently, pollution prevention projects are funded through a base's O&M budget. Funds are allocated through the Program Objective Memorandum (POM), which will have a separate account for pollution prevention in 1994. Air Force Material Command (AFMC) requested $2 billion and received only $200 million for pollution prevention (77). Shortfalls such as this will force pollution prevention projects to continue to compete for O&M funds.

All Civil Engineering (CE) projects are prioritized based on economic justification. This method allows projects to be compared on similar terms; however, current economic analysis only considers capital costs and operating expenses. This approach is adequate for traditional CE projects (minor construction, maintenance, and repair), but environmental projects involve more intangibles, and therefore require additional analysis. Future liability, civil lawsuits, compliance fines and fees, employee relations, potential productivity changes, and other costs associated with exposures to chemicals in the workplace are not quantified. Thus, a project using hazardous material could be selected over one that does not because potential intangible benefits or savings cannot be quantified.

The Approach. In September 1990 the EPA's Science Advisory Board (SAB) recommended that the "EPA should emphasize pollution prevention as the preferred option for reducing risk" (31:22). If risk reduction through pollution prevention is to be emphasized by the EPA, then risk reduction should be in the decision making process for prioritization and funding of pollution prevention projects. Therefore, any reduction in risk will inherently lower the probability of incurring expenses due to chemical exposures, accidents, civil suits, regulatory fines, and future liabilities.

In this analysis, risk reduction will be measured in terms of the probability of developing noncarcinogenic responses to chemical exposures -- either acute or chronic. Acute responses are caused by short duration exposures to toxic chemicals in excess of safe levels (16:331). Chronic noncarcinogenic responses are caused by repeated exposures to low concentrations of toxic chemicals that over a long period of time create an adverse health effect (16:332). Costs for both will be determined by the use of expected values. For chronic effects, the probability for developing an adverse effect will be determined by using a risk assessment. For acute effects, accident statistics will be used to determine the probability.

Specific Problem

Pollution prevention project justification must include economic factors not currently considered. Incorporating the economic benefits associated with the reduction of workplace chemical exposures is one possible way to improve the current economic analysis process. Therefore, the purpose of this thesis is to determine the costs associated with noncarcinogenic effects from exposure to chemicals in the workplace.

Research Objectives

The primary objective of this research is to determine the magnitude of the cost to the Air Force associated with chemical exposures in the workplace resulting in noncarcinogenic responses. The potential of developing a chronic response will be determined theoretically by using the risk assessment process. The significance of experiencing an acute response from exposure will be determined empirically through the gathering of accident data.

The secondary objective is to determine the cost. Costs will be determined by calculating expected values for chronic and acute effects.

Scope

This research will address direct and indirect costs associated with chemical exposures in the workplace such as lost productivity, time off work, and employer medical costs. Because of the difficulty in substantiating the relationship between carcinogenic effects and chemical exposures, this study will only address noncarcinogenic effects of exposure to toxic substances. The costs addressed are those incurred by the Air Force as an employer, they do not address intangibles such as the morale of the employees, and workers out-of-pocket expense.

II. Literature Review

Overview

The Pollution Prevention Act of 1990 requires all institutions that produce hazardous waste to develop and implement a pollution prevention program. Implementation of pollution prevention projects will, and should only, occur if the project's benefits outweigh the costs. As funding for national defense is cut, pollution prevention is becoming a useful method for trimming operation costs while maintaining an effective Air Force. To provide a more accurate analysis, risk reduction due to toxic chemical exposure needs to be quantified. To further explain the incorporation of risk reduction into economic analysis of pollution prevention projects, this chapter discusses hazardous materials, the Pollution Prevention Program, project funding, life cycle costing, total cost assessment, risk analysis, and workplace exposures.

Hazardous Materials

This research examines the effects of toxic materials as a subcategory of hazardous materials. To understand the difference between toxic and hazardous materials, both must be defined. There is no simple definition for a hazardous material, but the California Department of Health Services defines a "hazardous material" in the following manner:

> A Hazardous material is a substance or combination of substances which, because of its quantity, concentration, or physical, chemical or infectious characteristics, may either: (1) cause, or significantly contribute to an increase in mortality or increase in serious irreversible, or incapacitating reversible, illness; or (2) pose a substantial present or potential hazard to human health or environment when improperly treated, stored, transported or disposed of or otherwise managed. (68:13)

A hazardous waste is a byproduct of a hazardous material. The Resource Conservation and Recovery Act of 1976 (RCRA) defines a hazardous waste as a solid waste that possesses a hazardous characteristic or is specifically listed as hazardous. An operational definition of a hazardous waste is a substance that demonstrates one or more of the following properties: ignitability, corrosivity, reactivity, or toxicity (78:1).

Ignitability. Ignitability refers to a substance's ability to catch fire, or burst into flame spontaneously. Ignitable substances are defined as substances that have a flashpoint of less than 140°F (68:14).

Corrosivity. Corrosives have a pH of less than 2 or greater than 12.5 and are capable of destroying living tissue or 0.250 inches of steel per year through chemical reactions (68:14).

Reactivity. Reactive means the substance reacts violently with water, is explosive, or undergoes violent changes without detonating (68:14). Explosives and oxidizers are examples of reactive substances.

Toxicity. Toxicity is the ability of a substance to damage living tissue, impair the central nervous system, cause severe illness or, in extreme cases, death when ingested, inhaled, or absorbed through the skin (64:1167). Hence, a toxic substance is a type of hazardous material. The individual effect of a toxic substance depends upon many factors such as the exposure dose, the frequency of exposures, the duration of exposures, the pathway, and the individual's susceptibility to the chemical (68:129).

Effects may be acute or chronic. Acute toxicity refers to the ability to cause adverse effects after a single short-term exposure (16:331). Chronic toxicity refers to the ability to cause adverse health effects after repeated or long-term exposure (16:332).

Because of the wide variety of effects toxic substances can have on receptors and unknowns associated with toxic substances, "toxicity is objectively evaluated on the basis of test dosages made on experimental animals under controlled conditions" (64:1167). The LD_{50} (lethal dose to 50% of the population) and the LC_{50} (lethal concentration to 50% of the population) tests measure the potency of a substance, or the dose required to produce a specific effect (44:204).

The Occupational Safety and Health Administration (OSHA) has established Short Term Exposure Limits (STEL) for chemicals based on their LD_{50}. The STEL is a 15-minute time weighted average exposure limit which shall not be exceeded at any time during a work day (except for chemicals as specified) (17:45).

The Pollution Prevention Program

The Pollution Prevention Act of 1990 requires all organizations, public and private, to establish a systematic procedure designed to reduce or eliminate the generation of hazardous and non-hazardous wastes known as a pollution prevention program (7:197).

This program had the support of former President George Bush:

> Preventing pollution is a far more efficient strategy than struggling to deal with the problems once they've occurred...Its time to reorient ourselves, using technologies and processes that reduce or prevent pollution, to stop it before it stops. (5:1)

William K. Reilly, the former chief administrator of the EPA, further emphasizes this point:

> Let's make prevention of pollution the guiding philosophy of waste management. Let's assert a hierarchy of values that begins with pollution prevention. (5:1)

"Pollution prevention can be interpreted as any effort to reduce the quantity of industrial, hazardous, or toxic waste through changes in the waste generating or production process at the source" (5:112). The Act establishes a waste management hierarchy which is illustrated in Figure 1.

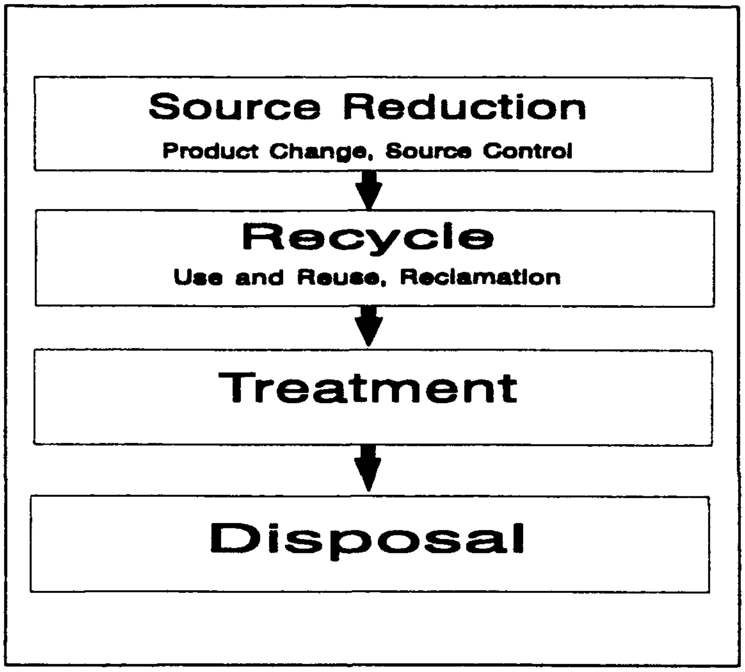

Figure 1. Waste Management Hierarchy

Source reduction, the preferred method, includes waste reduction at the point of generation, material substitution, production or process changes (40:4). These all reduce the amount of hazardous materials used and the subsequent amount of waste generated.

Closed-loop and on-site recycling are considered the next best alternatives because they reduce the amount of waste produced but they do not eliminate the need for, or the use of, hazardous materials (5:113). Closed-loop recycling is a method of continually recycling and reusing the product within the system. On-site recycling removes the waste from the system but the waste is recycled on-site.

Treatment consists of techniques to reduce the volume, toxicity, or mobility of the waste but is not considered pollution prevention because it does not reduce the actual amount of waste being generated (27:45).

The last alternative is disposal and should only be utilized when all other alternatives have been exhausted. Disposal only moves the waste to another location, it does not get rid of the problem.

History. In 1975 the 3M Corporation first implemented the approach of source reduction as a means of hazardous waste management at the corporate level by adopting "a corporate policy of attacking hazardous waste problems at their source" (68:176). In 1981 alone, 3M saved approximately $30 million dollars due to its pollution control program (68:176).

Laws such as the Comprehensive Environmental Restoration Cleanup and Liability Act (CERCLA) of 1980 provided further incentive to implement pollution prevention by establishing joint and several liability for the cleanups (45:181). Joint and several liability makes all generators of wastes responsible for the cleanup of sites in which their wastes were disposed of; even if the wastes were disposed of in compliance with the regulations in effect at that time. However, any one or more parties can be held solely responsible for the total cost of the cleanup, irregardless of the amount of wastes they disposed of at the site. This act strengthens the case for pollution prevention because it becomes difficult for environmental managers to predict what future regulations and disposal standards will require.

CERCLA was followed by the Hazardous & Solid Waste Amendment (HSWA) in 1984. HSWA greatly increased the number of wastes classified as hazardous under RCRA. It added to RCRA's cradle-to-grave law, which makes generators responsible for any future cleanups associated with the waste, even if the waste is properly disposed of (78:57). This act also put restrictions on land disposal and the treatment of chemicals (78:57). These restrictions dramatically increased disposal costs due to the decrease in possible disposal alternatives. In some areas, the cost for disposal of certain wastes has increased 2000 percent in 4 to 5 years (22:3). The increase in disposal costs spurs organizations to use pollution prevention as a means to reduce raw material, production, and waste disposal costs.

Finally, in 1990 the Pollution Prevention Act was passed, requiring all generators of hazardous waste to implement a pollution prevention program. This stresses source reduction as the preferred method of waste reduction.

EPA Policy. The EPA has indicated that pollution prevention is the preferred option for pollution control and risk reduction. The Science Advisory Board (SAB) reiterated this philosophy by stating that "end-of-pipe" controls and remediation are no longer sufficient policy (66:1). However, pollution prevention projects are still difficult to fund because current command and control policies do not provide incentives to reduce pollution below allowable limits (5:26).

The EPA has indicated that they intend to implement market-based incentives to encourage pollution prevention. Under their guidelines, "the major categories of incentive systems include: 1) pollution charges, 2) marketable permits, 3) deposit-refund systems, 4) removal of market barriers, and 5) revision of legal standards of liability" (66:15). The use of these systems provide monetary incentives by making it more cost effective to implement pollution prevention projects than to continue with current practices.

As the EPA moves toward market based incentives pollution prevention will become more and more attractive. For example, California's "label Law" sets standards on the amount of toxins permitted in food (15:325). If a manufacturer exceeds an established toxin content, the label must state this (15:325). The bad publicity caused by the label provides an incentive to keep the product's toxic level down.

Air Force Policy. The implementation strategy for the Air Force's Pollution Prevention Program as mandated by the Pollution Prevention Act of 1990, is laid out in Air Force Policy Directive 19-4. The Air Force developed a Pollution Prevention Manual to give specific guidance on program implementation (21:1-1). The Air Force's pollution prevention program relies on the opportunity assessment procedure developed by the EPA. The opportunity assessment consists of four steps; planning & organization, assessment, feasibility analysis, and implementation (21:3-1). The final step, implementation, requires the prioritization of projects because of limited funds (21:3-1). Costs incurred due to workplace exposures should be considered during the implementation phase.

Leadership's View on Pollution Prevention. The importance of pollution prevention is evident in this statement by the Secretary of Defense, Richard Cheney.

> I want the DOD to be the leader in agency environmental compliance and protection. Federal facilities, including military bases, must meet environmental standards. It must be a command priority at all levels. I want every command to be an environmental standard by which Federal Agencies are judged. (14:1)

The Air Force Chief of Staff, General Merrill McPeak, and the Secretary of the Air Force, Mr. Donald Rice, further emphasized pollution prevention in the following memo.

> The Air Force is committed to environmental leadership with the goal of preventing future pollution by reducing use of hazardous materials and releases of pollutants into the environment as near zero as possible. The key to meeting this goal is to quickly move away from dependence on hazardous materials in the operation and maintenance of our weapons systems and our bases. (49:1)

The importance of pollution prevention to the Air Force is obvious. As a large industrial-based entity, the Air Force uses considerable quantities of hazardous materials and generates vast amounts of hazardous wastes which become increasingly difficult and costly to dispose of.

Benefits. To promote pollution prevention, the EPA published the Pollution Prevention Benefits Manual which describes four different types of benefits: These benefits are summarized in Table 1.

Table 1. Pollution Prevention Benefits

Costs	Tier	Examples
Usual Costs	0	Equipment, material, labor, etc.
Hidden Costs	1	Monitoring, paperwork, permit requirements, etc.
Liability Costs	2	Future Liability, penalties, fines, etc.
Less Tangible Costs	3	Corporate image, community relations, etc.

(7:198)

Prevention benefits in tier 0 and 1 are capital and operational cost savings associated with the project. The potential benefits at these levels include reduced costs in disposal, training, utilities, permitting, administration, storage, handling, and procurement of hazardous materials (7:198). Liability and less tangible costs at tier 2 and 3 include a decrease in potential liability for future off and on-site clean ups, fines for noncompliance, property damage, personal injury, and increased community and employee support because of reductions in pollution (7:198).

Pollution prevention could also affect job safety. As the use of hazardous materials and/or the level of the chemical's toxicity decreases, the degree of adverse effects associated with accidents involving chemicals also decreases. Therefore, reductions in chemical exposures due to pollution prevention should benefit organizations by reducing the associated costs of workplace accidents involving chemical exposures. Hence, added benefits of an effective pollution prevention program includes reduced risk of criminal and civil liability, reduced operating costs, and improve employee morale, enhanced organizational image in the community, and improved public health and the environment (27:1).

Project Funding

Project funding is an obstacle to overcome in the implementation of many pollution prevention programs. Projects are submitted in the installation's Federal Agency Pollution Abatement and Prevention Budget (A-106 report) and if approved, generally receive funds from the base O&M budget (21:9). However, the Equipment Account, Military Construction Account, and the Defense Environmental Restoration Account (DERA) are available for use in some circumstances (21:9).

The Environmental Compliance (EC) Project Priority Framework for environmental compliance projects consists of three levels (21:9) as shown in Table 2.

Table 2.

Environmental Compliance Project Priority Framework

Level	Category	Examples
Level I	Fixing Noncompliance	Correcting Notice's of Violations or Notice of Noncompliance
Level II	Preventing Noncompliance	Projects required to stay in compliance
Level III	Environmental Investments	Pollution prevention, liability reduction, asbestos abatement, etc

In this framework, Level I projects fix noncompliance issues. These issues include all violations of regulatory statutes. Level II projects prevent noncompliance with environmental regulations by addressing the matter before it becomes a violation. Level III projects, such as pollution prevention, are considered environmental investments and are not driven by the same regulatory requirements as Level I and II (21:10).

With projects outnumbering the funds available each year, only Level I and II projects are being funded (76). This means that not all pollution prevention projects can be funded.

In fiscal year 1994, the POM will have a specific Program Element Code (PEC) for pollution prevention projects (47). However, this account promises to fall short of what is required for current pollution prevention projects awaiting funding (77). Therefore, prioritizing projects will be necessary. The Pollution Prevention Program Manual lists, in no particular order, a set of criteria on which project evaluation should be based (21:3-14).

- cost effectiveness
- ease of implementation
- impacts on the environment and safety
- size of volume reduction and toxicity reduction
- environmental, safety, and health regulation that govern the use and disposal of the substance
- short- and long-term potential liability; relative mobility of the pollutants in the environment as measured by its water solubility or vapor pressure (21:3-14)

Because no common standard unit of measure exists (e.g. money) the value or weight placed on each of the criteria may be arbitrary and therefore incomparable. For example, should cost effectiveness be considered a higher priority than future liability. When in fact, the cost related to the liability associated to one project may far exceed the cost effectiveness of the implementation of another project. The only way to ensure good economic, environmental, and political decisions are made is to put all these criteria into a common unit of measure, the dollar. This thesis attempts to enable environmental managers to put a dollar value on one of these criteria, toxicity reduction.

Life-Cycle Costing

Life-cycle costing is the method currently used by the Department of Defense (DOD) to analyze all projects. It requires the identification and amortization of cost-bearing activities associated with the product or system throughout its lifetime (7:195). Unfortunately, this economic analysis traditionally considers only capital and O & M costs.

The DOD began using life cycle costing in April 1965 after the Logistics Management Institute in Washington D.C. prepared a report, *Life Cycle Costing in Equipment Purchase*, demonstrating the benefits of this method (7:193). This report drastically changed how DOD procured major defense systems and equipment. It showed that O&M costs were a major part of the total cost and that initial costs should not be the only factor used to determine which products and systems should be acquired.

Because life cycle costing recognizes only capital and O & M costs, the full price of goods and services are not realized. The difficulty in using life-cycle costing for pollution prevention is incorporating things such as environmental degradation and future liability.

Total Cost Assessment

Economic analysis of pollution prevention is difficult because it has long time horizons, and has probabilistic benefits that traditional analysis do not include (27:58). The Total Cost Assessment (TCA) process takes these issues into consideration along with the traditional costs (27:58).

To account for tier 2 and 3 costs (liability, and less tangible costs) a total cost assessment should be used. A TCA includes direct costs, indirect costs, liability costs, and less tangible benefits. TCA also uses extended time horizons to account for the long term payback of pollution prevention.

TCA requires the determination of direct and as many indirect costs as possible. Then other indirect costs that are difficult to substantiate (because of their probabilistic nature) are added separately to the assessment. They are added separately to highlight their uncertainty and importance. The costs associated with the reduction of risk to workplace exposures is one of these additional costs that may add significantly to a projects worth.

Risk Analysis

To analyze potential chronic effects toxic chemicals can create, the risk analysis process is required. "Risk analysis is the gathering of, analysis of, and use of risk information to understand and communicate the full nature of the risk within the context of society's perspective on risk" (67).

Risk analysis is a complex and time consuming process that is typically broken into four separate methods:

- Hazard Identification
- Risk Assessment
- Risk Significance
- Risk Communication (16:5)

Hazard Identification. Hazard identification determines the type of injury or disease that a risk agent may produce or if it will produce an effect at all. Animal and/or human (epidemiological) studies are used to determine if a substance may present a risk. Epidemiological studies use statistical analysis of human exposures to determine if exposures to a substance can creates a health risk. Animal studies include in vivo animal bioassays and invitro and tissue culture tests. These studies involve the actual dosing of animals or cultures to determine the effects the substance has on the animal or culture.

Risk Assessment. A risk assessment is the process of gathering data that relates response to dose and combines it with possible human exposure data to calculate a risk to a specific exposure (45:191). The degree of risk from a chemical is a function of the chemical's toxicity and the actual exposure to the chemical. To obtain necessary information to assess these factors, the risk assessment process is divided into four parts:

- Source/Release Assessment
- Exposure Assessment
- Dose-Response Assessment
- Risk Characterization (16:55)

Source/Release Assessment. The source/release assessment is a procedure that quantifies and identifies the likelihood of a release of a risk agent from potential sources (16:55). To determine release potential techniques such as monitoring, modeling, statistical analysis, accident investigation, and performance testing are used.

Exposure Assessment. Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of exposure to agents present, or the estimating of a hypothetical exposure (16:65). To have an exposure there must be a source, pathway, and a receptor. Therefore, all three of these aspects are considered in this analysis.

All exposure routes, land, air, and water are examined in this procedure. An assessment is made on the potential for ingestion, inhalation and/or absorption of the substances and the environmental fate of the agent is also determined. The environmental fate depends on three factors: persistence, movement, and degradation of the agent (67).

Dose-Response Assessment. The dose-response assessment is a process of characterizing the relation between the dose of the agent administered or received and the incidence of an adverse health effect in exposed populations and estimating the incidence of the effect as a function of exposure to the risk agent (67). Animal and/or human studies are used to generate dose-response curves that quantify the biological response to dose levels (67). Typically, the dose-response curve has a sigmoidal shape as illustrated in Figure 2.

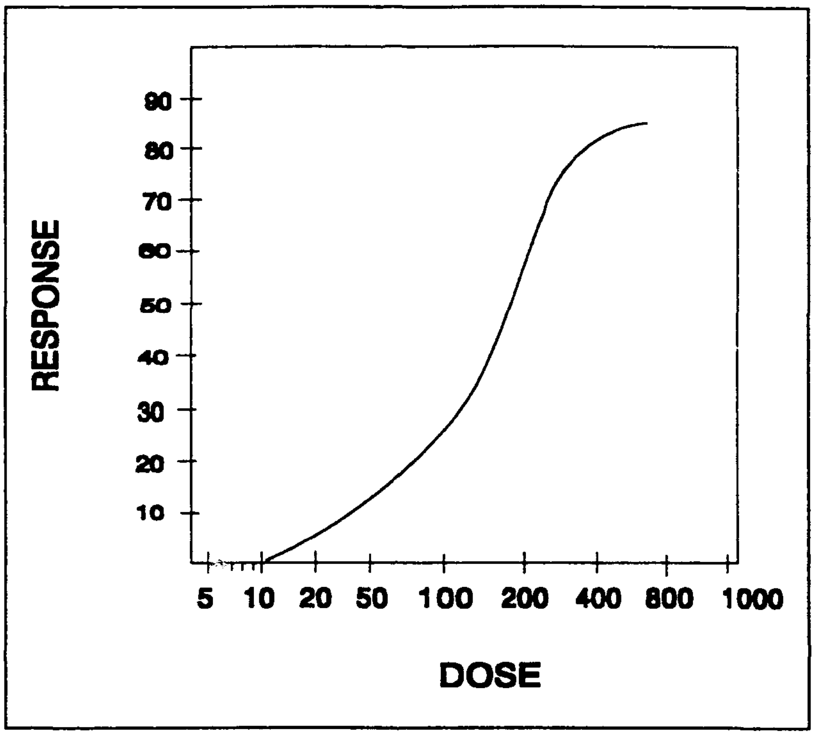

Figure 2. Dose-Response Curve (36:205)

Unlike carcinogens, noncarcinogens usually have a threshold value that indicates a safe dose below which no adverse health effects will be observed (68:131). The apparent intersection with the x-axis in Figure 2 implies the existence of this threshold dose (44:204). At the upper end the flattening of the curve reflec s a ceiling level of maximal response that cannot be increased by greater dose (44:204). This level may correspond to death in an individual or to 100% incidence of disease in a population (44:204).

The values for the different effect levels are determined through toxicological and/or epidemiological studies. For example, "the NOEL is defined as the lowest exposure level at which no statistical significant increases in frequency or severity of effects exists between the exposed population and its control" (28:1-2). Figure 3 illustrates the relationship between the different response values for noncarcinogenic effects.

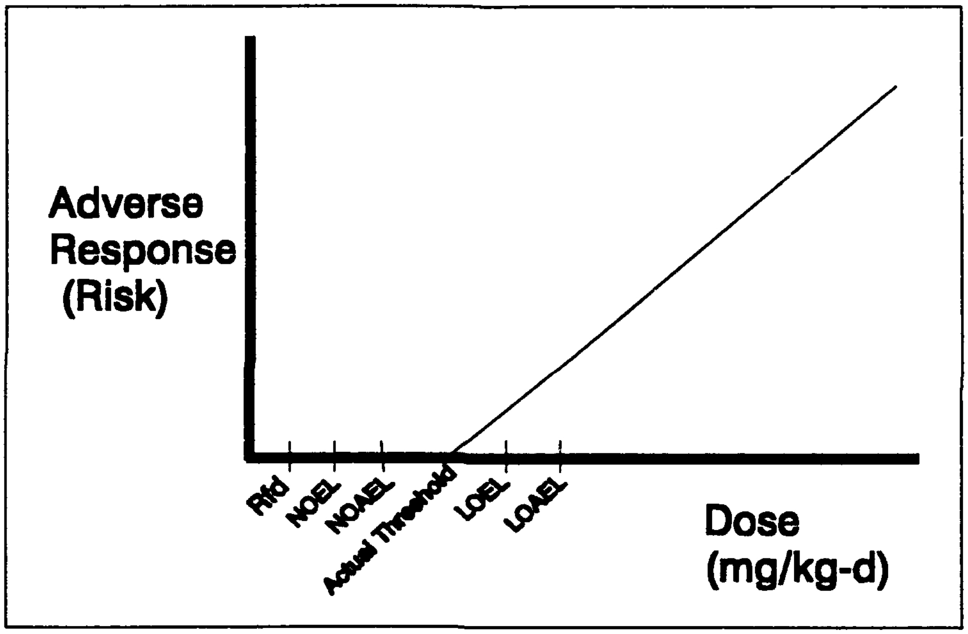

Figure 3. Measured Response Values (45:209)

Where

RfD = Reference Dose
NOEL = no-observable-effect level
LOEL = lowest-observable-effect level
LOAEL = lowest-observable-adverse-effect level
NOAEL = no-observable-adverse-effect level

The difference between the zero point and the threshold value is the safe dose, which is the actual dose of toxicant that can be taken up by the animal or human without having an adverse health effect. The EPA's estimate of this value is referred to as the reference dose (RfD) for oral uptake, or reference concentrations (RfC) for inhalation uptake. The reference dose/concentration is defined as the highest acceptable daily intake of a toxic chemical that does not produce an adverse health effect. The reference dose/concentration is based on the NOAEL, or the LOAEL if the NOAEL can not be determined (45:208). Equation 1 is the complete form of the RfD equation.

$$RfD=\frac{NOAEL \text{ or } LOAEL}{UF * MF} \tag{1}$$

Where

NOAEL = No Observable Adverse Effect Level
LOAEL = Lowest Observable Adverse Effect Level
UF = Uncertainty Factor
MF = Modifying Factor

The EPA adjusts the NOAEL or LOAEL by uncertainty and modifying factors to account for the uncertainties associated with the extrapolation of animal responses to human responses, and to account for the most sensitive individuals (45:208). A value of 10 is used for the uncertainty factor to account for variations in human sensitivity, for example children (45:209). If required, an additional 10-fold factor is used for each of the following extrapolations: from long-term animal studies to the case of humans, from a LOAEL to a NOAEL, and to expand from subchronic to chronic exposure (26:11). A modifying factor may be added to reflect professional assessment of the uncertainties of the study and data base not already covered in the uncertainty factors (26:12). The modifying factor can range from 1 to 10.

For example, suppose existing animal data for a (ficcitious) chemical indicates there is a LOAEL at 1000 mg/m^3. The EPA would establish a RfC as illustrated in Table 3.

Table 3.

Example of RfC Adjustment Factor Calculation		
Criteria	Uncertainty Factor	Modifying Factor
Adjustment "Human Sensitivity"	10	-
Animal Data to Human	10	-
LOAEL to NOAEL	10	-
Chronic Exposure Data Exists	-	-
Professional Assessment of Uncertainties	-	3
Cumulative Uncertainty & Modifying Factor	3000	

Therefore, the RfD for the chemical would be 0.33 mg/m^3 (1000 mg/m^3 / 3000) instead of 1000 mg/m^3 as the data indicated. These uncertainty and modifying factors can change the RfD's by many orders of magnitude for chemicals that lack sufficient toxicological data.

Risk Characterization. Risk characterization combines source/release assessments, dose-response assessments, and exposure assessments to develop an estimate of the types and magnitudes of the adverse effects that a risk agent may cause and the probability that each effect will occur (67). The risk associated with the exposure is determined in this phase using a hazard quotient, which is a ratio of the CDI to the RfD.

$$\textit{Hazard Quotient} = \frac{CDI}{RfD} \tag{2}$$

The hazard quotient provides a numerical indicator of the degree to which the potential exposure dose approaches a critical level; when the ratio exceeds unity (1.0), there is a potential hazard posed by the chemical(s) (67).

Determination of the effects created by exposures to multiple chemicals through various pathways has been addressed by the American Conference of Governmental Industrial Hygienists (ACGIH), the Occupational Safety and Health Administration (OSHA), the World Health Organization (WHO), and the National Research Council (NRC) (16:3-7). All groups recommending an approach chose some type of dose additive model (16:3-7). The model used by the EPA sums hazard quotients to determine an overall hazard index for an exposure.

When dealing with multiple exposures, each chemical may not effect the same part of the body (e.g. one chemical affects the liver, another the kidney). Therefore, dose additive models are not the most feasible method if the chemicals do not have the same target organ (67). Since the assumption of cumulative effects best fits chemicals with similar modes of action, a separate hazard index should be generated for each target organ (16:3-7). The hazard index is a numerical representation of the proximity to the acceptable exposure limit. As this value nears 1.00, the potential hazard increases (16:3-7).

Risk Significance. An acceptable risk is usually established at this point. It is based upon public opinion, current technology, and economic feasibility. This is done by weighing the risks of the alternatives to the activity giving rise to the risk and the evaluation of "tradeoffs between the benefits of incremental efforts to reduce risks and the costs of obtaining those benefits" (16:17).

Risk Communication. In this phase the risk posed, the significance of the risk, and decisions, actions, or policies to manage or control the risk are explained and discussed with all interested parties (16:4).

Workplace Exposures

There has been a proliferation of chemicals in industry with 60,000 to 70,000 chemicals currently in use (9:5). The use of these chemicals potentially increases the number of employees at risk due to exposure. The EPA's Acute Hazard Events (AHE) database keeps track of major acutely toxic substance releases in the U.S.. From 1980 to 1985 there were 6928 major accidents (9:15). Of these, 468 accidents involved human injury or death (138 deaths, 4717 injuries) (9:15).

Since the AHE database includes only major accidents, it would be reasonable to assume that more accidents occur resulting in minor injuries that are not tabulated by the EPA, but could have a significant cost associated to them. For example, from 1980-82 in California, 46.9% of the occupational illnesses among semiconductor workers resulted from exposure to toxic materials ("systemic poisoning") (68:419).

Accidents

Accidents are unintentional occurrences resulting in injury, property damage, or other losses. Even though workplace exposures to chemicals are designed to be below ACGIH Threshold Limit Values (TLVs) or OSHA Permissible Exposure Limits (PELs), excursions beyond these safe levels can occur which cause acute responses.

Furthermore, if the probability and financial impact of this type of accident can be determined, an expected value can be associated with the potential occurrence. For acute effects, the closer the concentration is to an exposure limit (e.g. Short Term Exposure Limit) the greater the potential for an accident. With a higher probability for mishaps the associated costs will also increase. This relation implies an expected value can be calculated for these accident costs. The generic equation would be:

$$EV = \sum_{i=1}^{n} P_i * C_i \qquad (3)$$

Where

P = Probability of accident occurrence
C = Cost associated with an accident

Costs associated with accidents can include wage loss, medical expense, workman's compensation, and indirect losses from work accidents. These indirect costs include time spent filling out accident reports, giving first aid to injured workers, and production time slowdowns and/or losses.

Conclusion

Pollution prevention is becoming an important part of environmental management in the Air Force. Pollution prevention has the support of the nation's leaders, but unless projects have adequate economic justification they will not be implemented. Economic analysis of pollution prevention projects must include more than capital and operating costs in the life cycle costing analysis to show all the benefits.

If in fact chemical-related accidents generate a cost to employers due to lost productivity, Workman's Compensation claims, and other indirect costs, the reduction in the number or severity of accidents by a pollution prevention project can provide economic benefits. These benefits should be used in project justification.

The significance of chemical exposure can be measured by the number of individuals exposed to toxic chemicals versus the number which suffer some adverse health effect due to the exposure (9:45). These health effects are measured in short-term (acute) illness, and longer term (chronic) (9:45).

An expected value can be used to determine costs associated with chemical exposures resulting in some form of noncarcinogenic effect. These expected values could than be used as estimates of potential cost savings resulting from risk reduction. These cost savings along with traditional economic analysis will provide better justification for project funding and implementation.

III. Chronic Noncarcinogenic Effects

Quantifying Exposure

There are a large number of chemicals in use with an even greater number of exposure scenarios existing within the Air Force. This chapter looks at generalized scenarios to determine if workplace exposures resulting in chronic health effects warrant detailed economic consideration.

Any exposure to a hazardous chemical above an established threshold level presents a certain health risk. The actual exposure in relation to this threshold level can be calculated using the risk assessment process. The following outlines how each step of the risk assessment process is used herein to quantify the risk and costs associated with chronic health effects brought on by workplace exposures.

Source/Release Determination. The source/release assessment determines where and how a toxic chemical is released (16:57). The sources to be examined are representative of the chemicals used by the Air Force either as a pure product or as a constituent in another product. These chemicals are to be selected through the examination of base supply documentation and Facility Annual Hazardous Waste Reports. This report is a mandatory report filed with the EPA by large scale generators of hazardous waste. It is, in part, a complete listing of the hazardous wastes disposed of by the facility.

For dermal exposure, the chemicals requiring analysis can be limited to chemicals with skin designations found in the OSHA "Limits For Air Contaminants" table located in 29 CFR 1910.1000. Currently, 146 chemicals carry a skin designation with their permissible exposure level (PEL). A skin designation means the chemical has the potential to be absorb through the skin and create an adverse health effect.

Exposure Determination. Exposure assessment estimates or directly measures the quantities or concentrations of risk agents received by individuals (16:65). Exposure levels can be entered into the EPA risk assessment model to determine if any exposures in excess of the reference dose exist. Exposure concentrations will be obtained from industrial hygiene surveys (conducted by bioenvironmental engineering). This data will then be checked to determine if exposures exceed safe limits or if multiple chemicals in the workplace present a cumulative risk which would result in a cost to the Air Force.

Dose-Response Determination. Dose-response determines the dose of risk agent received by the exposed individual and estimates the relationship between doses and the magnitude of their adverse effect (16:74).

Variations of equation 4 are used to calculate chemical intakes, in this case the CDI.

$$I = C * \frac{CR * EFD}{BW} * \frac{1}{AT} \tag{4}$$

Where

I = intake; the amount of chemical at the exchange boundary (mg/kg body weight-day)

Chemical-related variable

C = chemical concentration; the average concentration contacted over the exposure period (e.g., mg/L)

Variables that describe the exposure population

CR = contact rate; the amount of contaminated medium contacted per unit time or event (e.g., L/day)

EFD = exposure frequency and duration; describes how long and how often exposure occurs. Often calculated using two terms (EF and ED)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight; the average body weight over the exposure period (kg)

Assessment-determined variable

AT = averaging time; period over which exposure is averaged (days)

The normal routes of exposure for industrial chemicals in the workplace are inhalation and dermal absorption. Other routes of exposure, such as the direct ingestion of chemicals, are highly unlikely in the workplace and are not considered in this research (29:42).

The only variables unique to the inhalation route are the contaminant concentration in air (CA) which is expressed in (mg/m^3) and the inhalation rate (IR) which is expressed in (m^3/hour). The CA is determined by conducting air monitoring at the worksite. The inhalation rate on the other hand is dependent upon the exposed individuals degree of physical activity at the time of exposure. Depending upon the type of activity the EPA has established average inhalation rates for different types of people performing different types of tasks. Equation 5 (a variation of Equation 4) is the route specific equation used to calculate intake values for inhalation exposures.

$$\text{Intake (mg/kg-day)} = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \qquad (5)$$

Where

CA = Contaminant concentration in air (mg/m^3)

IR = Inhalation rate (m^3/hour)

ET = Exposure time (hours/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kg)

AT = Averaging time; period over which exposure is averaged (days)

The value used for the exposure duration (ED) can be questioned but becomes irrelevant for noncarcinogenic effects because as can be seen in equation 8 it factors out by appearing in both the numerator and denominator.

$$\frac{ED}{AT}=\frac{ED}{ED*365}=\frac{1}{365} \tag{6}$$

Therefore, the determination of the exact value for ED is not of importance for noncarcinogenic assessments. The averaging time is used to show the difference between noncarcinogenic and carcinogenic effects. For noncarcinogens, the averaging time is the duration of the exposure. For carcinogens, it is used to distribute the exposure over the individual's lifetime.

For the dermal route the only unique variables are the chemical concentration in water/solution (CW) which is expressed in (mg/liter), the skin surface area available for contact (SA) which is expressed in (cm^2), and the chemical-specific dermal permeability constant (PC) which is expressed in (cm/hr).

Values for skin surface area have also been determined by the EPA and averages for the exposed area should be used. The dermal permeability constant is the rate at which the chemical absorbs through the skin. These values are determined experimentally by dividing the absorption rate observed in the skin by the concentration applied. Equation 6 (another variation of Equation 4) is the route specific equation used to calculate intake values for dermal exposures.

$$\text{Absorbed Dose (mg/kg-day)} = \frac{CW \times SA \times PC \times ET \times EF \times ED \times CF}{BW \times AT} \qquad (7)$$

Where

CW = Chemical concentration in water/solution (mg/liter)

SA = Skin surface area available for contact (cm^2)

PC = Chemical-specific dermal permeability constant (cm/hr)

ET = Exposure time (hours/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

CF = Volumetric conversion factor for water (1 liter/1000 cm^3)

BW = Body weight (kg)

AT = Averaging time; period over which exposure is averaged (days)

Risk Characterization. Risk characterization is an estimate of the type and magnitude of adverse health effects that the risk agent may cause and the potential that each effect will occur (16:84). Once the intake value is determined the hazard quotient can be determined by the following equation:

$$Hazard\ Quotient = \frac{CDI}{RfD} \qquad (8)$$

Where

CDI = Chronic daily intake (mg/kg-day)
RfD = Reference dose (mg/kg-day)

Reference doses are obtained from the Health Effects Assessment Summary Tables (HEAST). These tables are published by the EPA explicitly for use in risk assessments.

<u>Multiple Exposures</u>. To account for the effect of multiple exposures, a hazard index for each type of end effect can be calculated. A hazard index is a summation of all hazard quotients across all the exposure routes and chemicals of concern. This procedure is illustrated in Table 4.

Table 4.

Chronic Hazard Index Estimate For Liver Lesions					
Exposure Chemical Index	CDI (mg/kg-d)	RfC / RfD (mg/kg-d)	Hazard Quotient	Pathway Hazard Index	Total Exposure Hazard Index
Exposure Pathway: Inhalation					
DDT	.0003	.0005	.6		
1,1-DCA	.06	.5	.12		
Toluene	.06	2	.03	.75	
Exposure Pathway: Dermal					
DDT	.00007	.0005	.14		
1,1-DCA	.01	.5	.02		
Toluene	.3	2	.15	.31	
Total Chronic Hazard Index					1.06

Taken sigularly, the hazard quotients from the individual chemical exposures do not represent a hazard; however, the chemical exposures are equivalent to an exposure with the potential to, in this case, cause liver damage.

Probability of Incidence Model. The probability of incurring a chronic noncarcinogenic effect is based on the dose-response curve for the chemical. These probabilities must be determined independently for each chemical because the concentration resulting in a 100% incidence rate for the effect of concern differs by chemical. As explained in the dose-response section, the curve is typically sigmoidal, but because of the difficulty in predicting the actual shape of the curve, a linear relationship will be used to approximate the curve.

Assuming response has a normal distribution, and the reference dose/concentration is approximately equal to the actual threshhold, a linear estimate of this curve can be made by using the LD_{50} or the LC_{50} as the midpoint as shown in Figure 4.

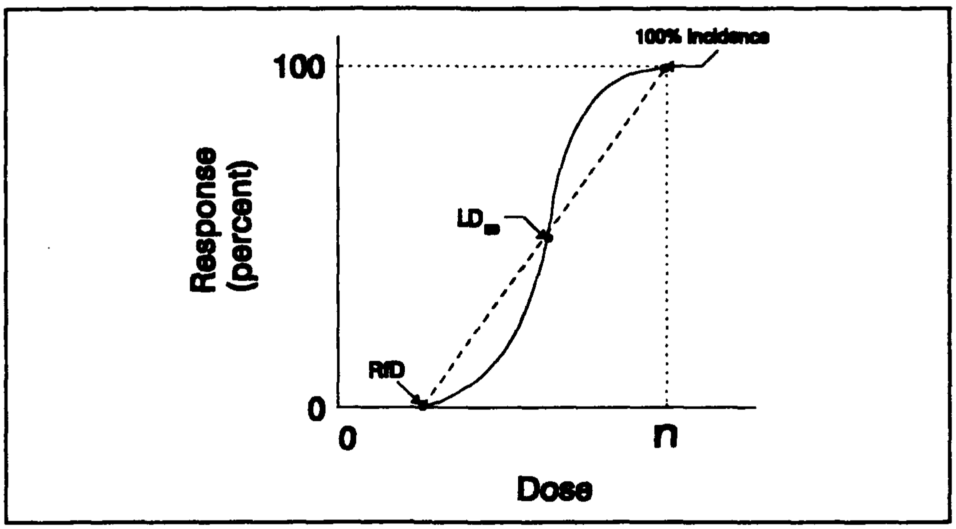

Figure 4. LD_{50} and Dose-Response Curve

With the hazard quotient for the LD_{50} or LC_{50} determined, an assumed hazard quotient value for 100% incidence is taken at twice the LD_{50} or LC_{50} hazard quotient. This concept is illustrated in Figure 5.

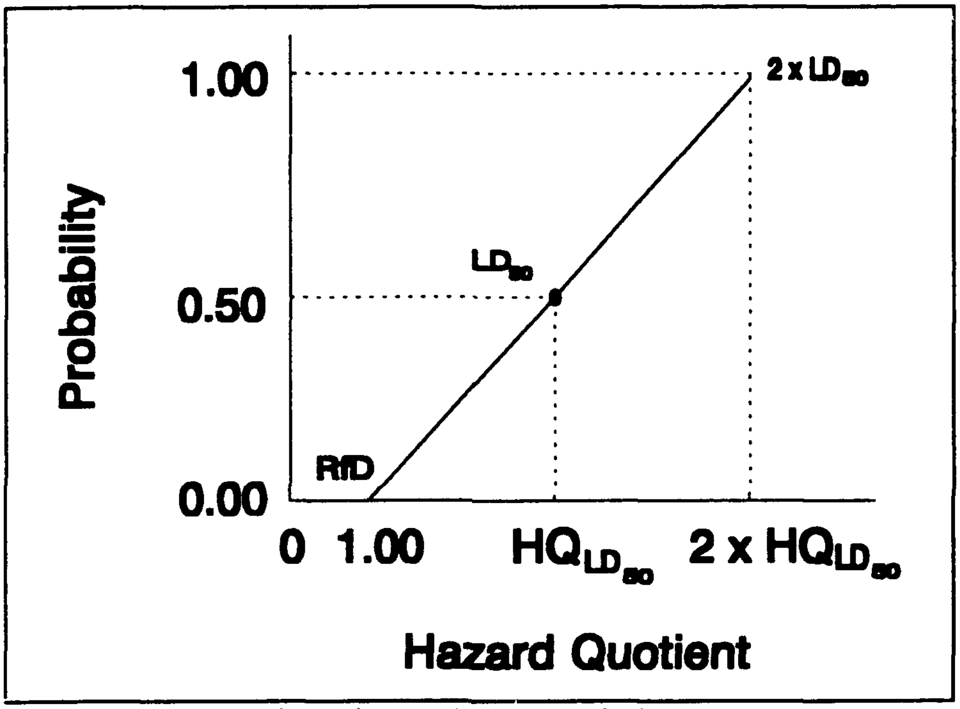

Figure 5. Estimation of Probability

This linear approximation intersects the sigmoidal curve at the midpoint and endpoints, giving reasonable values for this model.

Cost Estimation. To estimate the expected value incurred due to chronic noncarcinogenic effects, estimates of productivity losses and medical expenses must be calculated. The cost involved in replacing the worker will be used as the measure of productivity loss. This cost will be measured in terms of the replacement's salary. Medical costs must also be included, as measured by the average yearly costs for effects of concern.

Model Application

The intention of this part of the research was to develop a model to estimate costs associated to chronic exposures in the workplace and use pre-existing exposure data to validate the model. Much of the information required for this model could be found but the compilation of some specific exposure information, contaminant concentration, exposure time, and exposure frequency was not possible. This information is required to calculate the intake values (CDIs). The actual measuring (workplace monitoring) of this type of data is possible but is beyond the scope of this research. At this point, the model is based on theory and still requires validation. This can be accomplished by measuring or gathering the necessary workplace data.

The use of this model can help determine the cost of chronic exposures, and can be used as a tool to justify pollution prevention projects or further safety measures. This model is the only procedure we know of that takes known scientific procedures and incorporates them in a way to determine the relative safety of workplace conditions in regards to chronic health effects. An additional benefit of this model is that it puts workplace exposure into monetary terms. Thus, exposures to different chemicals can be compared on a universal scale, the dollar.

IV. Acute Noncarcinogenic Effects

Quantifying Exposure

Chemical accidents can occur in any workplace. The prevalence of chemicals in the Air Force range from aircraft maintenance workers exposed to hydrazine to administrators exposed to TCE in "liquid paper". If an accident can be linked to a toxic chemical and a cost determined, the removal of the chemical by a pollution prevention project will show a cost avoidance. This cost avoidance can be addended to the economic justification to show a more accurate representation of the project cost/benefit.

To determine the cost of acute injuries due to chemical exposures, this research will analyze recorded accident data. Since each data source provides different manipulations of accident data, a method is required to put the information in a common term, money. The steps in this analysis will include gathering accident data on chosen chemicals, determining the number and severity of accidents related to the specific chemicals, determining the total number of employees exposed, calculating the probability of a toxic chemical accident, determining the total cost for the accident, and calculating the expected value of the exposure from the cost per accident and the probability of the accident.

Accident Data

Chemical and cost data were obtained from the Air Force Environmental Health Office, the Bureau of Labor and Statistics, the National Safety Council, the Bureau of Workman's Compensation (BWC), the Air Force Safety Office, and the National Institute for Occupational Safety and Health (NIOSH). A cost of a chemical exposure injury and death will be estimated for use as a basis to determine the expected value of a chemical accident. Then, using the data from each organization, a probability of injury or death will be calculated. The cost will be multiplied by the probability to give a range of expected values for an injury or death.

Chemical Selection. The chemicals selected for this research effort were first limited to the EPA 17 targeted chemicals listed in Table 5 because the EPA is mandating their reduction in use.

Table 5.

Targeted Priority Chemicals for Hazardous Waste Reduction	
1. Benzene	10. Methyl Ethyl Ketone
2. Cadmium Compounds	11. Methyl Isobutyl Ketone
3. Carbon Tetrachloride	12. Nickel Compounds
4. Chloroform	13. Tetrachloroethylene
5. Chromium Compounds	14. Toluene
6. Cyanides	15. Trichloroethane
7. Dichloromethane	16. Trichloroethylene
8. Lead Compounds	17. Xylene(s)
9. Mercury Compounds	

To investigate toxic chemical usage throughout the Air Force, five bases were sampled for the 17 targeted chemicals. Hazardous material purchase or hazardous waste generation was used as an indicator of chemical use on that base. Bases were selected from 3 major commands, AETC, ACC, and AFMC. Three bases were selected from AFMC because it generate 80% of the hazardous waste in the Air Force (77). The other bases were selected to provide a broader representation of installations outside AFMC. Through personal or phone interviews with the Environmental Management office at each base, the most used chemicals were selected. The selection process was as follows:

1. Collect information on the total amounts used/purchased or disposed of from the 17 targeted chemicals list
2. Rank The chemicals by total volume used/purchased or disposed

The three most widely used/purchased/disposed chemicals with the potential to create significant acute effects were then selected. The three chemicals selected for further study were:

Methylene Chloride (DCM)

Methyl Ethyl Ketone (MEK)

Trichloroethylene (TCE)

Refer to Appendix E for a detailed description of the selected chemicals.

Accident Costs. Accident reports provide information on time lost due to injuries. Costs estimates can then be made for lost time with lost time, in terms workers salary, used as a measure for production lost. Medical and non-injured persons expenses include investigating and filling out accident reports, time spent administering first aid, and time lost by other non-injured workers due to work stoppages. These expenses will be calculated from the time spent on that activity multiplied by an average wage rate for the individual performing the activity. The assumptions are based on Wright-Patterson Medical Center estimates and USAF pay scales (including medical board and specialty pay, BAQ, and BAS). The average cost estimate of an accident injury is then determined by using the following averages:

Assumptions:

Workdays lost = 5.1 (50:2)

Medical visit = 2 hrs (1 hr w/ doctor + 1 hr w/ nurse)

Non-injured person involved = 10 people for 2 hrs

Supervisor's time on accident investigation = 2 hrs

Average labor rate for injured person = \$8.57/hr (E-5, @ 6 yrs)

Average labor rate for a doctor = \$23.23/hr (O-5 @ 16 yrs)

Average labor rate for a nurse = \$21.69/hr (O-4 @ 12 yrs)

Average labor rate of supervisor = \$10.66/hr (E-6, @ 10 yrs)

Calculations:

Workers cost = $8.57/hr x 8 hr/day * 5.1 days = $349.66

Medical costs = 1 hr * $29.98/hr + 1 hr * 21.69/hr = $51.67

Investigation & Reports = 2 hrs * $10.66/hr = $21.32

Lost production time = 10 workers * 2 hrs x $8.57/hr = $171.40

Total Cost = $594.05 (rounded to $600)

This total cost seems reasonable when compared to a National Safety Council (NSC) estimate of $420/worker as the amount of goods and services needed to offset the cost of an injury. The NSC estimate was not used because it is not the direct cost of an injury.

For fatalities additional expenses are incurred. They include workdays lost, medical costs, time spent on accident investigation, and lost production time. The cost of workdays lost is due to the fatality and is measured by the time spent to get an equivalent replacement and the replacement's salary. Medical costs are based on the time spent by an emergency room staff tending to the injury. The time spent on accident investigation is what the worker's supervisor spends while determining the cause of the accident and remediating it. The lost production time is for the other workers in the shop based on losing a half a day of production due to administering first aid and disruption of normal activities.

Using the injury data and time estimates, the average cost of an accident fatality becomes:

Assumptions:

Workdays lost = 6 months (180 days)

Medical visit = 20 manhours (4 hr x 2 doctors + 4 hr x 3 nurses)

Lost production time = 10 people for 4 hrs

Supervisor's time on accident investigation = 2 hrs

Average monthly salary for worker = $1370.70/mo (E-5, @ 6 yrs)

Average labor rate for a doctor = $29.98/hr (O-5 @ 16 yrs)

Average labor rate for a nurse = $21.69/hr (O-4 @ 12 yrs)

Average labor rate of supervisor = $10.66/hr (E-6, @ 10 yrs)

Calculations:

Workers cost = 6 mo * $1370.70/mo = $8,224.20

Medical costs = 8 hr * $29.98/hr + 12 hr * 21.69/hr = $500.12

Investigation & Reports = 2 hrs * $10.66/hr = $21.32

Lost production time = 10 workers * 4 hrs * $8.57/hr = $342.80

Total cost = $9,088.44 (rounded to $9,100)

The remaining analysis will use these numbers as an estimate for accident costs for determining expected value for chemical related accidents.

Data Analysis/Correlations

To implement this model, the required data consisted of lost work days due to a chemical exposure, related accidents, exposure data from the accident including chemical identification, and other costs associated with the accident. This data came from both military and civilian occupational injury statistics. Using this exposure data, the analysis will determine the correlation between specific chemicals and reported injuries. For military injuries, the acute exposure will also determine if any career field has a higher potential for incurring accidents as a result of chemical exposure. The data will also be checked to determine how chemical concentration affects the cost. For example, is there a linear or exponential relationship between the two.

Military Data Source

The Environmental Health Office tracks occupational exposures to chemicals, sound, asbestos and other workplace hazards. The Bioenvironmental Engineering Office collects occupational hazard data for compilation by Environmental Health. On the job accident data came from the U.S. Air Force Occupational & Environmental Health Directorate (OEHL) of Armstrong Laboratory at Brooks AFB (see Appendix A). The data was collected from the Air Force Form 190 (Occupational Injury Report) for the last 6 years (50:1). Overall there were 77 chemical-related accidents reported for a total of 388 lost days (50:2). The data was reported by exposure, accident cases, and lost work days.

For the three selected chemicals, only Methylene Chloride showed up in the database, and as a single exposure. The other two, MEK and TCE, may have been involved in the exposure, but listed under a less specific label such as "unidentified fumes"(50). In some cases, the same chemicals could have been listed under different categories in the database because they were described differently on the Form 190. The description detail of the chemicals varied widely in the database. For example, descriptions ranged from "exposure to hydrazine", to "large amounts of fumes". After analyzing the database it was found that the exposures could be grouped into the broader categories listed in Table 6.

Table 6. OEHL Chemical Categories

Cleaning Agents
Reagents
Fuels
Paints and Solvents
Chemicals (chlorine, ammonia, etc.)
Gases (carbon monoxide, fuel exhaust, etc.)
Other hazardous materials (mace, coal dust, etc.)

The distribution of accidents in each category was almost equal and therefore did not indicate any areas that needed further investigation.

When listed by the material agent (chemical) exposed to, each exposure was described differently. Many of the reported accidents involved a single worker. Only seven of the 77 cases had more than one worker exposed by the same incident.

AFSC Impact. The Air Force uses the Air Force Specialty Code (AFSC) as an identifier of the member's job type. When the OEHL data was broken down by specialty code (for both military and civilian workers), 44 of the 47 listed AFSCs were single injury occurrences. Of the other three codes, one no longer exists after the AFSC reorganization in January 1993. The other two showed occurrences of 3 injuries out of 8622 people assigned, and 4 injuries out of 1942 people assigned. Assuming the accident was related to the duty performed, that would imply the acute chemical accident probability for these AFSCs are, at most, 0.00035 and, 0.002 respectively. Taking the greatest probability (0.002), the expected value of an acute chemical exposure would be:

$$(0.002) * (\$600) = \$1.20/\text{employee}$$

Given the OEHL data, all the expected values for the other AFSCs are less than this cost, making the $1.20 estimate conservative, given the information available.

Civilian Data Sources

There is a wide range of sources for chemical accident information in the civilian sector. Many federal, or federally sponsored agencies compile these statistics. Also, industrial organizations such as the Chemical Products Association, keep accident statistics. Finally labor unions compile accident data for their own use.

The National Safety Council. The National Safety Council (NSC) is a non-profit national organization created to promote on and off the job safety (60:1). They publish a yearly pamphlet called "Accident Facts" (see Appendix B). These pamphlets give yearly nationwide statistics for all accidents.

The category of accidents that most closely represented the data required by this thesis was poisoning. Poisoning can include exposure through dermal and inhalation routes. The following is a listing of the applicable categories taken from the NSC pamphlet.

Table 7. Fatalities by Poisoning

Type of poisoning	AGE 15-24	AGE 25-44
Total	637	3891
Cleansing, polishing agents, disinfectants, paints, varnishes	1	1
Petroleum products, other solvents and vapors	20	31
Corrosives, caustics	1	2
Other, unspecified solids & liquids	4	17
Other gases and vapors	29	61
Total poisonings of concern	55	112

Only applicable poisoning categories, for the age brackets of concern were used. The age brackets of concern were from 15-24 years of age and 25-44 years of age because this best represents the military workforce population. The population used to calculate the incident rate represents the entire population, assuming all accidents are reported. Therefore, this incidence rate is probably low. Rates for the total number of accidents of concern to total number of accidents are shown in Table 8.

Table 8. Probability of Poisoning

Age group	15-24	25-44
Ratio of Poisonings of Concern vs. Total Poisonings	55/637 = 0.0863	112/3891 = 0.0288
Fatality/100,000 workers	1.3[a]	4.4[a]
Fatality/100,000 for poisoning of concern	0.0863 * 1.3 = 0.112	0.0288 * 4.4 = 0.127

[a] Fatality Rate from NSC data

Average ratio for all age groups:

$$(0.112 + 0.127)/2 = 0.120 \text{ deaths per } 100{,}000 \text{ workers}$$

To ensure conservative analysis, it will be assumed that 10% of the workforce is exposed to chemicals and also reports the accident. The same fatality rate would then be for a population of:

$$10\% \text{ of } 100{,}000 = 10{,}000$$

The adjusted average ratio for the poisoning of concern then becomes:

$$0.120 \text{ deaths}/10{,}000 \text{ workers} = 0.000012$$

The cost per worker then is:

$$(0.000012) * (\$9,100) = \$1.09$$

The OEHL database supports this conclusion, because in six years there has been no fatalities reported due to poisonings in the workplace. Therefore, the probability of 0.000012 is approximately the OEHL generated probability of 0.00. This data does not provide chemical specific information, therefore only general expected values can be generated.

The Texas Institute for Advancement of Chemical Technology. The Texas Institute for the Advancement of Chemical Technology (TIACT) publishes a yearly pamphlet called "Insights: Safety in the Workplace". This pamphlet compiles data from many sources and uses what is applicable to the chemical industry. This information is gathered to show the safety of the chemical industry, so it is probably not inclusive of all pertinent data.

The number of lost workday cases due to injuries was 3.1 cases per 100 full-time employees for the chemical industry (72:5). The major types of injuries cited were: burns, asphyxiations, concussions, fractures, contusions, and electric shock. The report did not break down the number of injuries by any particular category. Therefore a conservative expected value, which includes all injuries in the chemical industry, is:

$$(\text{lost days/injury}) * (\$/\text{lost day}) = (\$/\text{worker})$$

$$(.031) * (\$600) = \$18.60/\text{worker}$$

The records show 557 fatalities occurring in the chemical industry since 1972. Of these, 115 can be related to acute effects due to chemical exposure (chemical gases/vapors/liquids). The ratio of chemical accidents to total fatalities is then 115/557. There was an average of .375 deaths per 100 full-time workers for all injuries in the industry. The probability of death due to acute effects from chemical exposure is:

$$\frac{\textit{chemical deaths}}{\textit{total deaths}} * \frac{\textit{total deaths}}{\textit{workers}} = \frac{\textit{chemical deaths}}{\textit{workers}}$$

$$(115/557) * (0.375/100) = 0.000774$$

The expected value of this incidence rate is:

$$(.000774) * (\$9,100) = \$7.04/\text{worker}$$

Because of the specificity of the data base, these probabilities are only applicable to career fields in military that deal with chemicals every day as part of their job and do not relate directly to the rest of the military workforce.

The National Institute for Occupational Safety and Health. The National Institute for Occupational Safety and Health (NIOSH) is part of the Center for Disease Control under the Public Health Service within the Department of Health and Human Services (56:1). The NIOSH Laboratory in Cincinnati compile statistics from the National Occupational Exposure Survey (NOES) (see Appendix C).

This survey database lists either industries or occupations for which the NOES data indicated a potential exposure to listed chemical agents (56:1). The survey data was collected during 1981-1983 from a sample of 4,490 businesses employing 1.8 million workers (56:2). Potential exposure estimates are derived from surveyor observation of the actual chemical or a tradename known to contain the chemical (56:1). This survey was conducted nationwide.

The statistics were chemical specific including the three chosen chemicals; DCM, MEK, and TCE. The industry or occupation with comparable duties that have chemical exposure potential in the Air Force was broken out. The statistics by chemical are:

Dichloromethane. In the applicable industries of construction, manufacturing, and services, there were 1,003,922 total workers surveyed working with or near DCM. Of that number there were 1,653,648 exposures at an unknown level. An average of 65% of those exposed were not wearing Personal Protective Equipment (PPE).

Trichloroethylene. There were 312,835 total workers surveyed where they were exposed to TCE as part of the job. Of that number there were 424,735 exposures. An average of 67.6% were not wearing PPE.

Methyl Ethyl Ketone. There were 1,057,000 workers surveyed where they were exposed to MEK as part of the job. Of that number, there were 2,833,000 exposures. An average of 62.3% were not wearing PPE.

For the three chemicals, there were more exposures than workers in each case. The NIOSH definition of exposure includes any exposure to a chemical in the workplace. If an individual is exposed to two or more products that contained the chemical, this would be considered two or more exposures. This would account for the greater number of exposures than workers. The data provides an idea of the comparative level of exposure occurrences for each chemical. MEK is the source of the most exposures, almost twice the number of DCM exposures. The relative exposure to TCE was very small, one-fourth to one-seventh the number of DCM and MEK exposures respectively. PPE is also shown to highlight its use in civilian industry.

This data indicates the numbers of persons exposed to specific chemicals; however, the exposure routes is unknown. It does not provide any more information about exposures such as concentration, duration, or frequency. This survey consisted only of a walk-through inspection to see if the chemical was present and how many workers were working around it. Therefore, expected values cannot be calculated from this data.

<u>Occupational Safety and Health Administration</u>. The Occupational Safety and Health Administration (OSHA) defines safe workplace standards and investigates workplace accidents. Cheryl Smith, an investigator from the regional office in Chicago stated that accident information is not kept by OSHA, it is sent to the Bureau of Labor and Statistics (BLS) for compilation. Hence, OSHA data does not exist in the necessary form to calculate expected values.

Bureau of Labor and Statistics. The national BLS office was able to provide generalized data very similar to the NSC data. Their numbers support NSC statistics and are quoted extensively in their handbook. The BLS is a clearinghouse for data compiled by other government agencies, and they do not generate their own statistics. Because this data is not broken down into chemical related accidents, it cannot be used to calculate expected values for chemical exposures.

Bureau of Workman's Compensation. The Ohio Bureau of Workman's Compensation (BWC) compiles information on claims filed by workers who were injured on the job (see Appendix D)(13:1). These claims are filed by workers trying to recoup expenses caused by an accident.

There are 4,965,000 workers in the state of Ohio according to BWC (13:2). There were a total of 141,857 injury claims reported in 1990, averaging 19.2 lost work days per injury (13:2). This gave an Ohio worker one chance in 35 to be injured and file a claim in 1990. There were also 245 fatalities (13:2).

This data is broken down into general categories of injury and accident type. The categories most closely representing toxic chemical exposure, "contact with harmful substances" and "not otherwise classified", were used as a worst case scenario to approximate the needed data. These general categories represent 13,400 injuries or 9.4% of the total injuries for 1990. Using the 13,400 injuries and the total workers in Ohio, a probability of an injury in these categories is 0.002699. Using this probability of injury an expected value (using $600 per injury) is $1.62. The category "harmful substance" is not defined further, leading us to assume that the cost is underestimated because not all workers are exposed to toxic chemicals. If only 20% of the workers are exposed, the expected value would still be:

$$\frac{(0.002699)}{(0.20)} * (\$600) = \$8.10/\text{worker}$$

Included in the report were injuries broken down by chemical families, including Chlorine and its compounds, and Acetone and other Ketones.

Chlorine Compounds. This broad category includes the chemicals of interest, Methylene Chloride and Trichloroethylene. There were a total of 96 injuries in 1990 caused by chlorine compounds. This number represents 0.07% of the total injuries. Of these chlorine-related injuries, 30% were chemical burns and 70% were from "other occupational illnesses". These accidents were caused by chemical exposure, vehicle accidents and miscellaneous causes. The total number of actual chemical exposures resulting in accidents is 62, representing 0.04% of the total injuries (12). Using the total worker population of Ohio, this gives a probability of Chlorine injury of 0.000012. The expected value is:

$$(0.000012) * (\$600) = \$0.007/\text{worker}$$

This value is less than one cent and is representative of only the state of Ohio.

The entire work force of Ohio is not exposed to Chlorine compounds. Therefore the BWC expected value is understated. Using the number of chlorine exposure accidents (12) and an estimate of the Ohio workers exposed to DCM from the NOES data, another expected value can be obtained that will be more conservative. The number of workers nationwide exposed to DCM, according to the NOES of 4,490 businesses, is 1,003,922. Dividing that number by 50 gives an extremely conservative estimate of DCM exposures in Ohio. The number of DCM exposed workers for Ohio would be 20,078. Using the number of injuries for Ohio caused by chlorine exposure (12) gives a probability of 0.0031. Another expected value, combining NOES and BWC data would be:

$$(0.0031) * (\$600) = \$1.86/\text{worker}$$

Although either of these expected values can be taken as correct, the cost per worker is insignificant.

Acetone and other Ketones. This category includes the chemical of interest, Methyl Ethyl Ketone. There were a total of 14 injuries in 1990 caused by this chemical family. This represents only less than 0.01% of the total accidents. Of these injuries, 14% were chemical burns, 7% from eye injuries and 79% were from "other occupational illnesses". These accidents also were caused by chemical exposure, vehicle accidents and miscellaneous causes. The total number of actual chemical exposure caused accidents were 11 (11). The probability of a Ketone injury in Ohio is then 0.00002. This gives an expected value of:

$$(0.00002) * (\$600) = \$0.01/\text{worker}$$

As with earlier analysis, since the entire work force of Ohio is not exposed to Acetone compounds, the BWC expected value is therefore understated. Using the number of Acetone exposure accidents (11) and an estimate of the Ohio workers exposed to DCM from the NOES data, an expected value can be obtained that will be more conservative. The number of workers nationwide exposed to DCM, according to the NOES of 4,490 businesses, is 2,833,000. Dividing that number by 50 gives an extremely conservative estimate of DCM exposures in Ohio. The number of DCM exposed workers for Ohio would be 56,660. Using the number of injuries for Ohio caused by Acetone exposure (11) gives a probability of 0.00019. Therefore, the expected value, combining NOES and BWC data would be:

$$(0.00019) * (\$600) = \$0.11/\text{worker}$$

As before, either of these estimates of cost per worker is insignificant.

Conclusion

Given the data available, it seems that the existing safety programs makes the incidence of accidents due to the presence of toxic chemicals in the workplace of little economic concern. The military data from OEHL points out that the reported incidence rate is very low, 77 cases in 6 years for the entire Air Force. Of the three chemicals of concern, only methylene chloride appeared in the data base, resulting in one lost day. This would indicate that even though these are the most commonly used chemicals in the Air Force, injuries due to these chemicals are not a significant problem in terms of lost time. If the expected values of these potential accidents were used to analyze the total cost/benefit of pollution prevention projects, it would not adjust their costs/benefits significantly. The civilian workplace data appears to back up this statement. The BWC data shows the toxic chemical accident occurrence to be minuscule, with a probability of less than 0.01 in most cases. The BWC data gives expected values of less than one cent per worker.

Nationwide, there was an average of 18.8 lost workdays per accident (for all workplace accidents). From the BWC data there was an average of 10.7 lost workdays per chemical-caused accidents. The average lost workday for the military chemical accidents was 5.1 days per accident. This indicates that, in general military chemical accidents are less severe and cause less lost time. The average lost time is about half the average time lost for all workplace accidents.

When exposure accident expected values are compared to the pollution prevention project cost, their value does not add or detract significantly to the total project cost. Therefore, these accident costs should not be used as additional justification and measurement of pollution prevention projects.

V. Conclusion

Overall

The intention of this research is to determine if there is significant cost involved due to chemical exposures in the workplace resulting in noncarcinogenic effects. If there is a substantial cost resulting from these exposures, this cost avoidance could be included in pollution prevention project justification along with other terms such as capital and O&M costs. The cost of medical work, accident investigation, and time lost from the job should be included. This research has shown that associating an expected value cost with these health factors is difficult because the records are not specific enough given the information needed.

Chronic Exposures

This thesis established a model implementing the EPA's risk assessment process to determine the risk of incurring a chronic noncarcinogenic effect in the workplace. This part of the research was based on known scientific methods and theory. At this time some of the necessary information was unavailable for validating the model.

However, this model has the potential to provide users with accurate information on expected costs due to chronic exposures to chemicals in the workplace. These costs could be used in many applications including pollution prevention project justification, determining workplace safety conditions, and selection of toxic chemical alternatives and processes.

Acute Exposures

What we have found through analysis of statistical data is that the cost of workplace injuries (acute effects) for pollution prevention justification are economically insignificant in comparison to the total project cost. The cost of an accident ranged from $18.60 per worker per year for any type of injury to less than one cent per worker per year for accidents caused by exposure to a chlorine compound. The data from civilian sources practically mirrored the military numbers, given the detail of the information, and support this conclusion.

The BWC data represents all claims filed, and therefore may not include all accidents that occurred in the workplace. These accident costs were so insignificant that even if doubled or tripled would still be less than one dollar. Therefore, the data was considered, but was not as integral to the analysis as the other data. The information from the BWC points out the rarity of toxic chemical accident in the public sector. They in fact, represent less than 1% of the total number of injuries.

When these expected values are multiplied by the number of personnel exposed at a particular worksite, the total costs does not add significantly to the benefits obtained from a pollution prevention project. For example, in a worst case scenario using 10.1 lost days/accident (BWC data for chemical accidents), a salary for an E-8 @ 18 yrs (highest enlisted rank potentially exposed), and an accident probability of 0.031 (TIACT data), would yield an expected value of $44.23/worker. This value still would not be significant when compared to total costs of pollution prevention projects. Therefore, costs resulting from chemical accidents in the workplace should not be used as additional justification for pollution prevention projects.

Recommendations

We do not recommend further economic analysis of accidents resulting from chemical exposures due to their insignificant cost when compared to total project costs. This research did not include other costs associated with controlling exposure within acceptable limits, nor does it consider time lost due to illnesses that preclude wearing PPE required by working with the chemicals. These two issues may have significant costs associated with them and may warrant further consideration.

Efforts should be made to obtain the necessary data for the risk assessment process to validate the chronic noncarcinogenic model developed in this thesis. This would enable managers to see if there are any potential long term health benefits associated with the removal of hazardous chemicals via a pollution prevention project.

APPENDIX A

OEHL Database on Injuries due to Chemical Exposures

Lost Time per Mat Agent Breakdown

Mat Agent	Days Lost	Percent
AIRCRAFT CLEANING COMPOUND	1	0.3%
AIRCRAFT SOAP	2	0.5%
ALLERGIC REACTION TO CONTACT ALLERGEN	9	2.3%
ALLERGIC REACTION TO FABRIC	60	15.5%
ALLERGIC REACTION TO REAGENTS RXN	2	0.5%
AMMONIA VAPORS	5	1.3%
ANSULITE	6	1.5%
ARSENIC, METAL FUMES	114	29.4%
BERYLLIUM COPPER ALLOY	2	0.5%
BLUE LACQUER SPRAY PAINT	1	0.3%
CARBON MONOXIDE	7	1.8%
CEMEMNT SOLUTION	5	1.3%
CHEST PAIN, PRESSURE, SOB, NAUSEA	2	0.5%
CHLORINE GAS	4	1.0%
CHLORINE GASES	1	0.3%
CITRIKLEEN	1	1.5%
CONTACT WITH ADHESIVES, HYDRAULIC FLUIDS AND HAND CLEANER	6	1.5%
DIESEL FUEL	2	0.5%
EPOXY PRIMER	1	0.3%
APU FIRED INHALED A STRONG AMMONIA ODOR	1	0.8%
EXHAUST FUMES	4	1.0%
EXPOSED TO AMMONIA	7	1.8%
EXPOSED TO CHLORINE	1	0.3%
EXPOSED TO CYCLOHEXLAMINE VAPOR	3	0.8%
EXPOSED TO DICHLORODIFLUOPROMETHANE	1	0.3%
EXPOSED TO HYDRAZINE	1	0.3%
EXPOSURE TO FUMES	2	0.5%
EXPOSURE TO PAINT FUMES	1	0.3%
EXPOSURE TO SOLVENTS, JP-4, OILS	6	1.5%
EXPOSURE TO SPRAY PAINT	4	1.0%
FIBERGLASS CARPET FIBERS	7	1.8%
FREON LEAK THROUGH AC UNIT	4	1.0%
GASOLINE AND ENGINE OIL	3	0.8%
HC SMOKE INHALATION	6	1.5%
HEADACHES WHEN AROUND JP-4 VAPORS	3	0.8%
HYDRAULIC (SKYDROL) FLUID	1	0.3%
HYDRAULIC FLUID	2	0.5%
HYDROCARBON EXPOSURE	2	0.5%
INHALATION TO JP-4	1	0.3%
JET ENGINE QUICK START	1	0.3%
JET FUEL AND HYDRAULIC FLUID	3	0.8%
JP-4	8	2.1%
JP-4 FUEL	2	0.5%
JP-4 SPLASHED IN EYES	1	0.3%
LARGE AMOUNTS OF FUMES	1	0.3%

Mat Agent (Continued)	Days Lost	Percent
LEAD BASED PAINTS	7	1.8%
LITHOGRAPHIC BLANKET WASTE	4	1.0%
MACE	1	0.3%
METHYLENE CHLORIDE	1	0.3%
PAINT FUMES	1	0.3%
PD-680	2	0.5%
PERCHLOROETHLENE FUMES/DEGREASER VAT	3	0.8%
PLASTIC RESIN, PLASTIC HARDENER	17	4.4%
POSSIBLE CHRONIC INHALATION GLUE	14	3.6%
POTENTIAL XYLENE VAPOR EXPOSURES	5	1.3%
REACTION TO FIBERGLASS	3	0.8%
SPRAYING A POLYURETHANE PAINT	7	1.8%
SYPHON JPTS FROM PORTABLE TANK WITH A GARDEN HOSE	2	0.5%
UNIDENTIFIED FUMES	1	0.3%
WASHRACK	2	0.5%
WELDING CADMIUM COATED BOLTS	2	0.5%
Total	388	100.0%

Mean per MAT AGENT group = 5.1
StdDev = 15.84

Number of Accidents per Mat Agent Breakdown

Mat Agent	# of Cases	Percent
AIRCRAFT CLEANING COMPOUND	1	1.3%
AIRCRAFT SOAP	1	1.3%
ALLERGIC REACTION TO CONTACT ALLERGEN	1	1.3%
ALLERGIC REACTION TO FABRIC	1	1.3%
ALLERGIC REACTION TO REAGENTS RXN	1	1.3%
AMMONIA VAPORS	1	1.3%
ANSULITE	6	7.8%
ARSENIC, METAL FUMES	3	3.9%
BERYLLIUM COPPER ALLOY	1	1.3%
BLUE LACQUER SPRAY PAINT	1	1.3%
CARBON MONOXIDE	1	1.3%
CEMENT SOLUTION	1	1.3%
CHEST PAIN, PRESSURE, SOB, NAUSEA	1	1.3%
CHLORINE GAS	2	2.6%
CHLORINE GASES	1	1.3%
CITRIKLEEN	1	1.3%
COAL DUST, SMOKE	3	3.9%
CONTACT WITH ADHESIVES, HYDRAULIC FLUIDS AND HAND CLEANENER	1	1.3%
DIESEL FUEL	1	1.3%
EPOXY PRIMER	1	1.3%
EPU FIRED INHALED A STRONG AMMONIA ODOR	1	1.3%
EPU FIRED INHALED STRONG AMMONIA ODOR	3	3.9%
EXHAUST FUMES	2	2.6%
EXPOSED TO AMMONIA	1	1.3%
EXPOSED TO CHLORINE	1	1.3%
EXPOSED TO CYCLOHEXLAMINE VAPOR	1	1.3%
EXPOSED TO DICHLORODIFLUOPROMETHANE	1	1.3%
EXPOSED TO HYDRAZINE	1	1.3%
EXPOSURE TO FUMES	1	1.3%
EXPOSURE TO PAINT FUMES	1	1.3%
EXPOSURE TO SOLVENTS, JP-4, OILS	1	1.3%
EXPOSURE TO SPRAY PAINT	1	1.3%
FIBERGLASS CARPET FIBERS	1	1.3%
FREON LEAK THROUGH AC UNIT	1	1.3%
GASOLINE AND ENGINE OIL	1	1.3%
HC SMOKE INHALATION	1	1.3%
HEADACHES WHEN AROUND JP-4 VAPORS	1	1.3%
HYDRAULIC (SKYDROL) FLUID	1	1.3%
HYDRAULIC FLUID	1	1.3%
HYDROCARBON EXPOSURE	1	1.3%
INHALATION TO JP-4	1	1.3%
JET ENGINE QUICK START	1	1.3%
JET FUEL AND HYDRAULIC FLUID	1	1.3%
JP-4	2	2.6%
JP-4 FUEL	1	1.3%
JP-4 SPLASHED IN EYES	1	1.3%
LARGE AMOUNTS OF FUMES	1	1.3%

Mat Agent (Continued)	Days Lost	Percent
LEAD BASED PAINTS	1	1.3%
LITHOGRAPHIC BLANKET WASTE	1	1.3%
METHYLENE CHLORIDE	1	1.3%
PAINT FUMES	1	1.3%
PD-680	1	1.3%
PERCHLOROETHLENE FUMES/DEGREASER VAT	1	1.3%
PLASTIC RESIN, PLASTIC HARDENER	1	1.3%
POSSIBLE CHRONIC INHALATION GLUE	1	1.3%
POTENTIAL XYLENE VAPOR EXPOSURES	1	1.3%
REACTION TO FIBERGLASS	1	1.3%
SPRAYING A POLYURETHANE PAINT	1	1.3%
SYPHON JPTS FROM PORTABLE TANK WITH A GARDEN HOSE	1	1.3%
UNIDENTIFIED FUMES	1	1.3%
WASHRACK	1	1.3%
WELDING CADMIUM COATED BOLTS	1	1.3%
Total	77	100.0%

Accidents per AFSC breakdown

AFSC	Civ	Mil	Total
None	17	5	22
0303	1	0	1
24270	0	1	1
3414	1	0	1
3703	1	0	1
4204	2	0	2
42355	0	1	1
42373	0	1	1
42652	0	1	1
43151	0	2	2
45252	0	1	1
45274	0	1	1
452X1	0	1	1
45453	0	1	1
4s470A	1	0	1
45652	0	1	1
45730	0	1	1
45750	0	1	1
45770E	0	1	1
457X2	0	1	1
45832	0	1	1
4607	1	0	1
46150	0	1	1
46250	0	3	3
46270	0	1	1
47532	0	1	1
4840	1	0	1
54552	0	1	1
54572	0	1	1
545X2	0	1	1
55150	0	1	1
55170	0	1	1
56651	0	4	4
5873	1	0	1
60251	0	1	1
60350	0	1	1
62350	0	1	1
631X0	0	1	1
64551	0	1	1
67252	0	1	1
70270	0	1	1
70330	0	1	1
81150	0	1	1
81152	0	1	1
81170	0	1	1
8255	2	0	2
92430	0	1	1
9756	0	1	1
Total	28	49	77

APPENDIX B

1991 Accident Facts on Work-Related Injuries

Between 1912 and 1991, accidental work deaths per 100,000 population were reduced 81 per cent, from 21 to 4. In 1912, an estimated 18,000 to 21,000 workers' lives were lost. In 1991, in a work force more than triple in size and producing 11 times the goods and services, there were only 9,900 work deaths.

	Workers (000)[a]	Deaths	Death Rates[b]	Disabling Injuries[c]
All Industries	116,400	9,900[c]	9	1,700,000
Agriculture[d]	3,200	1,400	44[e]	140,000
Mining, quarrying[d]	700	300	43	30,000
Construction	5,900	1,800	31	180,000
Manufacturing	18,200	800	4	310,000
Transportation and public utilities	6,000	1,300	22	140,000
Trade[d]	26,800	1,000	4	320,000
Services[d]	37,800	1,700	4	330,000
Government	17,800	1,600	9	250,000

Source: National Safety Council estimates (rounded) based on data from the National Center for Health Statistics.

[a] From state vital statistics and industrial commissions

[b] Numbers of workers are based on Bureau of Labor Statistics data and include persons aged 14 and over.

[c] Deaths per 100,000 workers in each group. 'About 3,500 of the deaths and 100,000 of the injuries involved motor vehicles.

[d] Agriculture includes forestry and fishing; Mining and quarrying includes oil and gas extraction (preliminary MSHA reports indicate 115 deaths in coal, metal, and nonmetal mining in 1991). Trade includes wholesale and retail trade. Services includes finance, insurance and real estate.

[e] Agriculture rate excludes deaths of persons under 14 years of age. Rates for other industry divisions do not require this adjustment. Deaths of persons under 14 are included in the agriculture death total

NATIONAL OCCUPATIONAL EXPOSURE SURVEY AS OF: 04/19/93
ESTIMATED TOTAL AND FEMALE EMPLOYEES
FIELD OBSERYATION AND TRADENAME DATA

CODE	DESCRIPTION	TOTAL WORKERS	FEMALE WORKERS	PERCENT CONTROLLED: NO CONTROL	RESPIRATORY PROTECTION	PERSONAL PROTECTION OTHER THAN RESPIRATORY	VENTILATION	OTHER CONTROL	EXPOSURES
HAZARD									
47270	DICHLOROMETHANE								
07	AGRICULTURAL SERVICES	5350	1813	100.0%	0.0%	0.0%	0.0%	0.0%	5613
13	OIL AND GAS EXTRACTION	14494	0	98.5%	0.0%	1.5%	0.0%	0.0%	28092
15	GENERAL BUILDING CONTRACTORS	27271	34	37.6%	0.0%	61.7%	0.7%	0.0%	56300
16	HEAVY CONSTRUCTION CONTRACTORS	32195	1260	93.5%	0.2%	1.7%	4.6%	0.0%	53575
17	SPECIAL TRADE CONTRACTORS	61237	454	97.3%	0.0%	0.9%	1.8%	0.0%	71580
20	FOOD ANO KINDRED PRODUCTS	25515	1910	86.0%	0.6%	9.1%	2.1%	2.3%	31360
22	TEXTILE MILL PRODUCTS	26992	2808	56.1%	0.1%	23.2%	20.7%	0.0%	33324
23	APPAREL AND OTHER TEXTILE PRODUCTS	115884	100700	69.9%	0.0%	0.0%	30.1%	0.0%	126720
24	LUMBER AND WOOD PRODUCTS	10642	3564	90.8%	0.0%	6.4%	2.8%	0.0%	19888
25	FURNITURE AND FIXTURES	15056	1779	80.4%	0.0%	15.2%	4.3%	0.0%	15903
26	PAPER AND ALLIED PRODUCTS	51677	10401	84.4%	0.0%	13.4%	2.1%	0.1%	65136
27	PRINTING AND PUBLISHING	111827	20882	81.3%	0.0%	11.5%	6.8%	0.4%	165848
28	CHEMICALS AND ALLIED PRODUCTS	44865	9907	43.3%	2.0%	33.0%	19.0%	2.8%	75898
29	PETROLEUM AND COAL PRODUCTS	6044	160	70.7%	0.0%	29.3%	0.0%	0.0%	8469
30	RUBBER AND MISC. PLASTICS PRODUCTS	38712	11774	51.0%	2.1%	15.1%	30.3%	1.4%	49808
32	STONE, CLAY, AND GLASS PRODUCTS	13016	1112	83.3%	0.0%	8.7%	7.0%	1.0%	18579
33	PRIMARY METAL INDUSTRIES	24765	215	83.7%	0.0%	15.6%	0.7%	0.0%	43339
34	FABRICATED METAL PRODUCTS	55185	21074	56.9%	0.5%	23.4%	18.5%	0.6%	77232
35	MACHINERY, EXCEPT ELECTRICAL	132090	24234	53.9%	2.0%	26.6%	16.6%	0.8%	236598
36	ELECTRIC AND ELECTRONIC EQUIPMENT	66856	31847	68.6%	0.1%	17.9%	11.3%	2.2%	103218
37	TRANSPORTATION EQUIPMENT	67915	8112	56.4%	7.0%	29.1%	6.1%	1.3%	123741
38	INSTRUMENTS AND RELATED PRODUCTS	40409	16986	72.9%	0.0%	15.2%	10.8%	1.2%	49869
39	MISCELLANEOUS MANUFACTURING INDUSTRIES	20527	11388	76.6%	0.6%	13.1%	9.7%	0.0%	24924
41	LOCAL AND INTERURBAN PASSENGER TRANSIT	1737	0	70.3%	0.0%	0.0%	29.7%	0.0%	1737
42	TRUCKING AND WAREHOUSING	19324	606	77.6%	0.0%	17.0%	5.3%	0.0%	22528
44	WATER TRANSPORTATION	2926	0	26.3%	36.9%	36.9%	0.0%	0.0%	4633
45	TRANSPORTATION BY AIR	33674	458	80.9%	0.1%	9.0%	8.5%	1.6%	76902
48	COMMUNICATION	30483	851	99.6%	0.0%	0.0%	0.4%	0.0%	38635
49	ELECTRIC, GAS, AND SANITARY SERVICES	53124	461	44.4%	0.0%	41.4%	14.2%	0.0%	116416
50	WHOLESALE TRADE - DURABLE GOODS	14573	213	73.6%	0.0%	23.4%	3.1%	0.0%	26949
51	WHOLESALE TRADE - NONDURABLE GOODS	5343	431	53.2%	0.0%	34.6%	12.2%	0.0%	7092
55	AUTOMOTIVE DEALERS & SERVICE STATIONS	37813	426	83.3%	0.0%	3.9%	12.8%	0.0%	44165
72	PERSONAL SERVICES	33961	19117	81.3%	0.0%	16.8%	1.8%	0.0%	49718
73	BUSINESS SERVICES	46808	7576	37.3%	0.0%	46.6%	15.3%	0.7%	137773
75	AUTO REPAIR, SERVICES, AND GARAGES	57857	0	94.4%	0.6%	0.0%	2.8%	2.2%	80692
76	MISCELLANEOUS REPAIR SERVICES	20729	0	98.4%	0.0%	0.0%	1.6%	0.0%	35383
80	HEALTH SERVICES	61940	35749	63.0%	0.1%	29.3%	7.5%	0.0%	84803
84	MUSEUMS, BOTANICAL, ZOOLOGICAL GARDENS	1734	164	100.0%	0.0%	0.0%	0.0%	0.0%	5019

ESTIMATED TOTAL AND FEMALE EMPLOYEES
FIELD OBSERVATION AND TRADENAME DATA

CODE	DESCRIPTION	TOTAL WORKERS	FEMALE WORKERS	NC CONTROL	RESPIRATORY PROTECTION	PERSONAL PROTECTION CTHER THAN RESPIRATORY	VENTILATION	OTHER CONTROL	EXPOSURES
73790	ETHYLENE, TRICHLORO-								
07	AGRICULTURAL SERVICES	1694	1694	100.0%	0.0%	0.0%	0.0%	0.0%	1694
15	GENERAL BUILDING CONTRACTORS	5462	3105	37.6%	2.5%	59.9%	0.0%	0.0%	9358
16	HEAVY CONSTRUCTION CONTRACTORS	5419	5306	100.0%	0.0%	0.0%	0.0%	0.0%	5419
17	SPECIAL TRADE CONTRACTORS	1879	1286	100.0%	0.0%	0.0%	0.0%	0.0%	1879
20	FOOD AND KINDRED PRODUCTS	2062	604	62.8%	0.0%	35.6%	1.6%	0.0%	2586
21	TOBACCO MANUFACTURES	516	0	0.0%	0.0%	100.0%	0.0%	0.0%	516
22	TEXTILE MILL PRODUCTS	26846	21509	2.0%	1.3%	4.1%	84.3%	8.3%	28031
23	APPAREL AND OTHER TEXTILE PRODUCTS	12[illegible]5	1188	94.1%	0.0%	1.0%	4.9%	0.0%	3769
24	LUMBER AND WOOD PRODUCTS	4931	1189	100.0%	0.0%	0.0%	0.0%	0.0%	5979
25	FURNITURE AND FIXTURES	1352	0	0.0%	0.0%	0.6%	50.0%	49.4%	2704
26	PAPER AND ALLIED PRODUCTS	4331	1846	65.0%	0.0%	20.6%	14.4%	0.0%	4331
27	PRINTING AND PUBLISHING	26316	10227	90.8%	0.0%	3.1%	3.9%	2.3%	27903
28	CHEMICALS AND ALLIED PRODUCTS	10276	3151	2.7%	0.0%	50.2%	42.4%	4.7%	16151
29	PETROLEUM AND COAL PRODUCTS	2020	0	100.0%	0.0%	0.0%	0.0%	0.0%	2020
30	RUBBER AND MISC. PLASTICS PRODUCTS	15771	2380	81.3%	1.3%	10.4%	3.8%	3.2%	25282
31	LEATHER AND LEATHER PRODUCTS	65	0	100.0%	0.0%	0.0%	0.0%	0.0%	65
32	STONE, CLAY, AND GLASS PRODUCTS	1494	1340	62.1%	2.7%	2.7%	19.7%	12.9%	1826
33	PRIMARY METAL INDUSTRIES	5047	417	42.1%	0.0%	29.5%	22.1%	6.3%	5387
34	FABRICATED METAL PRODUCTS	49043	30064	84.4%	1.5%	8.8%	5.2%	0.2%	53310
35	MACHINERY, EXCEPT ELECTRICAL	22210	2785	48.6%	0.0%	25.4%	21.9%	4.1%	30850
36	ELECTRIC AND ELECTRONIC EQUIPMENT	96999	47713	26.6%	0.8%	19.0%	29.5%	24.1%	165710
37	TRANSPORTATION EQUIPMENT	9304	559	51.7%	0.0%	20.4%	21.7%	6.2%	11749
38	INSTRUMENTS AND RELATED PRODUCTS	16292	5032	42.6%	0.0%	33.2%	22.3%	1.8%	20682
39	MISCELLANEOUS MANUFACTURING INDUSTRIES	6261	2937	70.0%	0.0%	1.4%	28.2%	0.4%	6802
40	RAILROAD TRANSPORTATION	261	0	100.0%	0.0%	0.0%	0.0%	0.0%	261
42	TRUCKING AND WAREHOUSING	5851	5071	99.8%	0.0%	0.2%	0.0%	0.0%	5851
45	TRANSPORTATION BY AIR	15216	3781	86.7%	0.0%	1.3%	7.6%	4.3%	16128
48	COMMUNICATION	8776	1801	43.6%	0.0%	56.4%	0.0%	0.0%	8776
49	ELECTRIC, GAS, AND SANITARY SERVICES	4335	429	100.0%	0.0%	0.0%	0.0%	0.0%	4335
50	WHOLESALE TRADE - DURABLE GOODS	3735	2260	100.0%	0.0%	0.0%	0.0%	0.0%	4390
51	WHOLESALE TRADE - NONDURABLE GOODS	703	0	0.0%	0.0%	100.0%	0.0%	0.0%	1407
55	AUTOMOTIVE DEALERS & SERVICE STATIONS	6692	0	100.0%	0.0%	0.0%	0.0%	0.0%	7376
72	PERSONAL SERVICES	1044	70	18.0%	0.0%	82.0%	0.0%	0.0%	2304
73	BUSINESS SERVICES	12973	3475	24.8%	0.0%	28.7%	46.6%	0.0%	22057
75	AUTO REPAIR, SERVICES, AND GARAGES	11197	4860	100.0%	0.0%	0.0%	0.0%	0.0%	11677
76	MISCELLANEOUS REPAIR SERVICES	812	0	100.0%	0.0%	0.0%	0.0%	0.0%	812
80	HEALTH SERVICES	11301	9059	66.9%	0.5%	32.0%	0.5%	0.0%	15080
84	MUSEUMS, BOTANICAL, ZOOLOGICAL GARDENS	1642	164	100.0%	0.0%	0.0%	0.0%	0.0%	3285

ESTIMATED TOTAL AND FEMALE EMPLOYEES
FIELD OBSERVATION AND TRADENAME DATA

CODE	DESCRIPTION	TOTAL WORKERS	FEMALE WORKERS	NO CONTROL	RESPIRATORY PROTECTION	PERSONAL PROTECTION OTHER THAN RESPIRATORY	VENTILATION	OTHER CONTROL	EXPOSURES
13980 BUTANONE, 2-									
13	OIL AND GAS EXTRACTION	29880	0	86.8%	0.0%	0 0%	13.2%	0.0%	66032
15	GENERAL BUILDING CONTRACTORS	61833	756	50.8%	5.2%	33.5%	10.6%	0.0%	97310
16	HEAVY CONSTRUCTION CONTRACTORS	28450	94	54.9%	9.0%	4.7%	31.4%	0.0%	51651
17	SPECIAL TRADE CONTRACTORS	205193	800	76.0%	3 4%	11.2%	9.3%	0.0%	337065
20	FOOD AND KINDRED PRODUCTS	18866	3026	85.0%	1.2%	10.3%	3.6%	0.0%	28289
21	TOBACCO MANUFACIURES	80	0	100.0%	0.0%	0.0%	0.0%	0.0%	80
22	TEXTILE MILL PRODUCTS	11714	2767	46.7%	0.0%	24.8%	28.6%	0.0%	30269
23	APPAREL AND OTHER TEXTILE PRODUCTS	3663	818	94.7%	0.0%	1.8%	3.6%	0.0%	4845
24	LUMBER AND WOOD PRODUCTS	36841	12284	52.1%	3.9%	8.3%	28.8%	7.0%	84882
25	FURNIIIJRE AND FIXTURES	65038	24686	17.6%	12.1%	22.4%	39.4%	8.5%	330669
26	PAPER ANO ALLIED PRODUCTS	25643	5063	57.0%	1.9%	16.3%	24.8%	0.0%	42594
27	PRINT1NG AND PUBLISHING	33294	9945	66.5%	0.0%	22.7%	10.7%	0.0%	45713
28	CHEM1CALS AND ALLIED PRODUCTS	44703	10026	21.2%	1.4%	34.8%	39.0%	3.6%	80758
29	PETRDLEUM AND COAL PRODUCTS	11678	416	74.7%	0.2%	19.7%	5.4%	0.0%	24283
30	RUBBER AND MISC. PLASTICS PRODUCTS	85284	28614	36.6%	6.6%	11.8%	44.5%	0.5%	159565
31	LEATHER AND LEATHER PRODUCTS	16196	11109	58.2%	0.0%	0.6%	38.5%	2.6%	27314
32	STONE. CLAY, AND GLASS PRODUCTS	13743	3068	24.6%	0.8%	34.4%	40.2%	0.0%	20049
33	PRIMARY METAL INDUSTRIES	20612	1461	41.3%	0.2%	14.7%	43.6%	0.1%	44496
34	FABRICATED METAL PRODUCTS	77258	26090	43.9%	3.6%	21.3b	21.8%	9.4%	155877
35	MACHINERY, EXCEPT ELECTRICAL	126424	17898	49.4%	4.4%	18.7%	25.3%	2.2%	270960
36	ELECTR1C AND ELECTRONIC EQU1PMENT	62277	29708	59.2%	1.1%	21.6%	16.2%	1.8%	122438
37	TRANSPORTATION EQUIPMENT	109387	12747	42.0%	11.1%	30.2%	13.8%	2.8%	523153
38	INSTRUMENTS AND RELATED PRODUCTS	32763	10355	69.8%	0.2%	18.4%	10.3%	1.3%	42284
39	MISCELLANEOUS MANUFACTURING INDUSTRIES	21743	6400	17.0%	6.9%	13.3%	50.2%	12.6%	92645
40	RAILROAD TRANSPORTATION	1268	0	1.7%	0.0%	98.3%	0.0%	0.0%	1268
41	LOCAL AND INTERURBAN PASSENGER TRANSIT	4702	0	80.4%	18.1%	1.4%	0.0%	0.0%	7872
42	TRUCKING AND WAREHOUSING	6014	65	51.8%	13.7%	12.2%	22.3%	0.0%	12851
44	WATER TRANSPORTATION	2753	0	0.4%	42.8%	56.6%	0.1%	0.0%	139631
45	TRANSPORTATION BY AIR	34878	500	49.2%	13.6%	16.7%	12.3%	8.2%	421476
48	COMMUNICATION	12080	571	99.5%	0.0%	0.2%	0.2%	0.0%	18876
49	ELECTRIC, GAS, AND SANITARY SERVICES	56542	658	71.3%	0.1%	25.4%	3.2%	0.0%	172203
50	WHOLESALE 1RADE - DURABLE GOODS	29488	5698	60.2%	0.0%	24.1%	14.9%	0.8%	46356
51	WHOLESAIE TRADE - NONDURABLE GOODS	8310	431	40.2%	0.0%	49.4%	10.3%	0.0%	16775
55	AUTOMOTIVE DEALERS & SERVICE STATIONS	11847	426	62.6%	0.0%	18.7%	18.7%	0.0%	27389
72	PERSONAL SERV1CES	8144	5735	86.0%	0.0%	0.0%	14.0%	0.0%	56400
73	BUSINESS SERVICIS	28133	6592	39.9%	2.1%	15.5%	37.6%	5.0%	41243
75	AUTO REPAIR, SERVICES, AND GARAGES	67900	470	76.8%	4.6%	2.6%	13.0%	2.9%	113539
76	MISCELLANEOUS REPAIR SERVICES	13529	672	100.0%	0.0%	0.0%	0.0%	0.0%	29650
80	HEALTH SERV1CES	17552	5241	69.1%	0.6%	21.9%	7.5%	0.9%	27714
84	MUSEUMS. BOTANICAL. ZOOLOGICAL GARDENS	1734	164	75.9%	24.1%	0.0%	0.0%	0.0%	6492

APPENDIX D

OHIO WORKMAN'S COMP. STATEWIDE
1990 INJURY/ILLNESS STATISTICS

NUMBER OF INJURIES REPORTED	141857
NONFATAL LOST DAYS	2719773
AVERAGE DAYS LOST PER INJURY	19.2
FATALITIES	245
DISABLING INJURY INVOLVING DISMEMBERMENT DISFIGUREMENT OR LOSS OF USE	850
DISABLING INJURIES OVER 7 DAYS	97605
DISABLING INJURIES 7 DAYS OR LESS	43157

NATURE OF INJURY	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
AMPUTATIONS	765	0.5	203570	266.1
BURNS	4179	2.9	52911	12.7
CONTUSIONS	13311	9.4	126710	9.5
DISLOCATIONS	2926	2.1	95945	32.8
FOREIGN BODY IN EYE	3515	2.1	15075	4.3
FRACTURES	13003	9.2	442424	34.0
LACERATIONS/PUNCTURES	15346	10.8	161539	10.5
SPRAINS/STRAINS	60436	42.6	1036807	17.2
CUMULATIVE TRAUMA DISORDERS	7584	5.3	124259	16.4
OTHER OCCUPATIONAL ILLNESSES	5242	3.7	146010	27.8
MULTIPLE INJURIES	9185	6.5	208090	22.7
NOT ELSEWHERE CLASSIFIED	101	0.1	2242	22.2
NOT STATED	6264	4.4	104191	16.6
TOTAL	141857	100.0	2719773	19.2
PART OF BODY				
EYES	5873	4.1	42331	7.2
HEAD	2311	1.6	26522	11.5
FACE & NECK	3606	2.5	48468	13.4
BACK	28359	20.0	469254	16.5
TRUNK/INTERNAL ORGANS	15550	11.0	413610	26.6
ARMS	17319	12.2	313259	18.1
HANDS	6575	4.6	122942	18.7
FINGERS	14684	10.3	331524	22.6
LEGS	18283	12.9	344121	18.8
FEET, TOES	7636	5.4	147747	19.3
MULTIPLE MAJOR BODY PARTS	17808	12.5	328501	18.4
INTERNAL SYSTEMS	3073	2.2	120870	39.3
NOT STATED	780	0.5	10624	13.6
TOTAL	141857	100.0	2719773	19.2
TYPE OF ACCIDENT OR EXPOSURE				
CAUGHT IN, ON, OR BETWEEN	12913	9.1	409963	31.8
CONTACT TEMP EXTR/FIRE/EXPLOSN	3160	2.2	48619	15.4
CONTACT W/ELEC. CURRENT	316	0.2	7953	25.2
FALL: SAME LEVEL	15611	11.0	295568	18.9
FALL: DIFFERENT LEVEL	7983	5.6	201551	25.3
CONTACT W/HARMFUL SUBSTANCES	4954	3.5	107248	21.6
MOTOR VEHICLE ACCIDENTS	5239	3.7	123301	23.5
STRIKING AGAINST	10229	7.2	151451	14.8
STRUCK BY FLY/FALLING OBJECTS	21751	15.3	277794	12.8
SLIPS(NOT FALLS)/BODILY REACTN	7338	5.2	119553	16.3
OVEREXERTION	39118	27.6	742023	19.0
NOT ELSEWHERE CLASSIFIED	8445	5.9	150922	17.9
NOT STATED	4800	3.4	83827	17.5
TOTAL	141857	100.0	2719773	19.2

AGE	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
15 AND YOUNGER	152	0.1	2204	14.5
16 THRU 19	7506	5.3	104230	13.9
20 THRU 24	19334	13.6	313683	16.2
25 THRU 34	47192	33.3	858279	18.2
35 THRU 44	34946	24.6	676541	19.4
45 THRU 54	20151	14.2	428373	21.3
55 THRU 64	10175	7.2	262431	25.8
65 AND OLDER	1229	0.9	52275	42.5
NOT STATED	1172	0.8	21757	18.6
TOTAL	141857	100.0	2719773	19.2
SEX				
MALES	96387	67.9	1927387	20.0
FEMALES	45470	32.0	792386	17.4
TOTAL	141857	100.0	2719773	19.2
ACCIDENT CAUSE				
WORK SURFACES	10120	7.1	219866	21.7
ELEVATION	196	0.1	5098	26.0
FLOOR	2402	1.7	51522	21.4
LADDER/SCAFFOLD	2217	1.6	55357	25.0
ROAD	1454	1.0	28057	19.3
STAIR/STEP	1973	1.4	35437	18.0
MISC WORK SURFACE	1878	1.3	44395	23.6
MATERIALS	21765	15.3	353807	16.3
MINERAL ITEM (BRICK,ETC)	1809	1.3	32051	17.7
DUST/PARTICLE (IN EYE)	972	0.7	3699	3.8
GLASS	472	0.3	6300	13.3
LUMBER/WOODWKG MATERIAL	1990	1.4	32554	16.4
METAL ITEMS/PARTS	14039	9.9	232263	16.5
TEXTILES	383	0.3	8566	22.4
MISC MATERIALS	2100	1.5	38374	18.3
CONTAINER/FURNTURE/FIXTURE	24851	17.5	424505	17.1
FURNITURE/FIXTURES	4229	3.0	71651	16.9
CONTAINER	15808	11.1	273386	17.3
DOOR/WINDOW/GATE/FENCE	1476	1.0	22778	15.4
FORM/FRAME/MOLD	94	0.1	1555	16.5
RACK/SHELF	1332	0.9	22187	16.7
SKID/PALLET	1912	1.3	32948	17.2
MACHINES	16075	11.3	400136	24.9
CASTING/FORGING/WELDING	1016	0.7	11712	11.5
CUTTING/SLICING MACHINE	1246	0.9	26549	21.3
DRILLING/BORING/TURNING	725	0.5	13644	8.8
ELEVATOR/CRANE/CONVEYOR	3259	2.3	79940	24.5
BUFFER/GRINDER/SANDER	1203	0.8	15838	13.2
PRESS	1572	1.1	57561	36.6
STATIONARY SAW	680	0.5	32848	48.3
MISC MACHINE	6374	4.5	162044	25.4
VEHICLES	14577	10.3	310933	21.3
AUTOMOBILE	1799	1.3	43870	24.4
FORKLIFT	2096	1.5	49490	23.6
HAND TRUCK/CART/ETC	2053	1.4	33864	16.5
HEAVY CONSIRUCTN EQUIP	462	0.3	10541	22.8
TRUCK/TRACTOR/VAN	5209	3.7	105314	20.2
MISC VEHICLE	2958	2.1	67854	22.9
HAND TOOLS	11573	8.2	171905	14.8
ELECTRIC HAND TOOL (EXCLUDE SAW)	777	0.5	10982	14.1
HAMMER/SLEDGE	907	0.6	13175	14.5
KNIFE/RAZOR	1724	1.2	16220	9.4

ACCIDENT CAUSE (CONTINUED)	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
PNEUMATIC HAND TOOL	927	0.6	14839	16.0
PORTABLE HAND SAW	314	0.2	4832	15.4
ROPE/CHAIN/CABLE	449	0.3	9404	20.9
SHOVEL/SPADE	381	0.3	6753	17.7
WRENCH - NON-MECH.	1012	0.7	15391	15.2
MISC HAND TOOL	5082	3.6	80309	15.8
HOT/FLAMMABLE SUBSTS	890	0.6	19084	21.4
FIRE/FLAME	203	0.1	9432	46.5
GREASE (HOT)	124	0.1	1583	12.8
HOT WATER/STEAM	102	0.1	1187	11.6
MOLTEN/HOT METAL	188	0.1	2817	15.0
MISC HOT/FLAMMABLE SUBST	273	0.2	4065	14.9
DANGEROUS CHEMICALS/DUSTS	4194	3.0	106454	25.4
ACID/ALKALI	229	0.2	2658	11.6
MISC SOAPS/DETERGENTS	425	0.3	4961	11.7
EXPLOSIVE/NOXIOUS DUST	599	0.4	52885	88.3
PETROLEUM PRODUCTS	1261	0.9	21993	17.4
MISC CHEMICAL/DUST	1680	1.2	23957	14.3
MISC CAUSES	37812	26.6	713083	18.9
INJURY BY ANOTHER	9434	6.6	168361	17.8
PERSON INJURED	2911	2.0	60105	20.6
ICE/SNOW	2626	1.8	50391	19.2
NOT ELSEWHERE CLASSIFIED	15492	10.9	303433	19.6
NOT STATED	7349	5.2	130793	17.8
TOTAL	141857	100.0	2719773	19.2

OHIO WORKMAN'S COMP.
ACETONE & OTHER KETONES
1990 INJURY/ILLNESS STATISTICS

NUMBER OF INJURIES REPORTED	14
NONFATAL LOST DAYS	399
AVERAGE DAYS LOST PER INJURY	28.5
FATALITIES	0
DISABLING INJURY INVOLVING DISMEMBERMENT DISFIGUREMENT OR LOSS OF USE	0
DISABLING INJURIES OVER 7 DAYS	10
DISABLING INJURIES 7 DAYS OR LESS	4

NATURE OF INJURY	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
AMPUTATIONS	0	0.0	0	0.0
BURNS	2	14.3	20	10.0
CONTUSIONS	0	0.0	0	0.0
DISLOCATIONS	0	0.0	0	0.0
FOREIGN BODY IN EYE	1	7.1	3	3.0
FRACTURES	0	0.0	0	0.0
LACERATIONS/PUNCTURES	0	0.0	0	0.0
SPRAINS/STRAINS	0	0.0	0	0.0
CUMULATIVE TRAUMA DISORDERS	0	0.0	0	0.0
OTHER OCCUPATIONAL ILLNESSES	11	78.6	376	34.2
MULTIPLE INJURIES	0	0.0	0	0.0
NOT ELSEWHERE CLASSIFIED	0	0.0	0	0.0
NOT STATED	0	0.0	0	0.0
TOTAL	14	100.0	399	28.5
PART OF BODY				
EYES	3	21.4	23	7.7
HEAD	0	0 0	0	0.0
FACE & NECK	0	0.0	0	0.0
BACK	0	0.0	0	0.0
TRUNK/INTERNAL ORGANS	0	0.0	0	0.0
ARMS	0	0.0	0	0.0
HANDS	1	7.1	1	1.0
FINGERS	0	0.0	0	0.0
LEGS	0	0.0	0	0.0
FEET, TOES	0	0.0	0	0.0
MULTIPLE MAJOR BODY PARTS	0	0.0	0	0.0
INTERNAL SYSTEMS	10	71.4	375	37.5
NOT STATED	0	0.0	0	0.0
TOTAL	14	100.0	399	28.5
TYPE OF ACCIDENT OR EXPOSURE				
CAUGHT IN, ON, OR BETWEEN	0	0.0	0	0.0
CONTACT TEMP EXTR/FIRE/EXPLOSN	0	0.0	0	0.0
CONTACT W/ELEC. CURRENT	0	0.0	0	0.0
FALL: SAME LEVEL	0	0.0	0	0.0
FALL: DIFFERENT LEVEL	0	0.0	0	0.0
CONTACT W/HARMFUL SUBSTANCES	13	92.9	396	30.5
MOTOR VEHICLE ACCIDENTS	0	0.0	0	0.0
STRIKING AGAINST	0	0.0	0	0.0
STRUCK BY FLY/FALLING OBJECTS	1	7.1	3	3.0
SLIPS(NOT FALLS)/BODILY REACTN	0	0.0	0	0.0
OVEREXERTION	0	0.0	0	0.0
NOT ELSEWHERE CLASSIFIED	0	0.0	0	0.0
NOT STATED	0	0.0	0	0.0
TOTAL	14	100.0	399	28.5

AGE	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
15 AND YOUNGER	0	0.0	0	0.0
16 THRU 19	1	7.1	8	8.0
20 THRU 24	1	7.1	10	10.0
25 THRU 34	6	42.9	78	13.0
35 THRU 44	4	28.6	56	14.0
45 THRU 54	2	14.3	247	123.5
55 THRU 64	0	0.0	0	0.0
65 AND OLDER	0	0.0	0	0.0
NOT STATED	0	0.0	0	0.0
TOTAL	14	100.0	399	28.5
SEX				
MALES	10	71.4	315	31.5
FEMALES	4	28.6	84	21.0
TOTAL	14	100.0	399	28.5
ACCIDENT CAUSE				
WORK SURFACES	0	0.0	0	0.0
ELEVATION	0	0.0	0	0.0
FLOOR	0	0.0	0	0.0
LADDER/SCAFFOLD	0	0.0	0	0.0
ROAD	0	0.0	0	0.0
STAIR/STEP	0	0.0	0	0.0
MISC WORK SURFACE	0	0.0	0	0.0
MATERIALS	0	0.0	0	0.0
MINERAL ITEM(BRICK,ETC)	0	0.0	0	0.0
DUST/PARTICLE (IN EYE)	0	0.0	0	0.0
GLASS	0	0.0	0	0.0
LUMBER/WOODWKG MATERIAL	0	0.0	0	0.0
METAL ITEMS/PARTS	0	0.0	0	0.0
TEXTILES	0	0.0	0	0.0
MISC MATERIALS	0	0.0	0	0.0
CONTAINER/FURNTURE/FIXTURE	0	0.0	0	0.0
FURNITURE/FIXTURES	0	0.0	0	0.0
CONTAINER	0	0.0	0	0.0
DOOR/WINDOW/GATE/FENCE	0	0.0	0	0.0
FORM/FRAME/MOLD	0	0.0	0	0.0
RACK/SHELF	0	0.0	0	0.0
SKID/PALLET	0	0.0	0	0.0
MACHINES	1	7.1	3	3.0
CASTING/FORGING/WELDING	0	0.0	0	0.0
CUTTING/SLICING MACHINE	0	0.0	0	0.0
DRILLING/BORING/TURNING	0	0.0	0	0.0
ELEVATOR/CRANE/CONVEYOR	0	0.0	0	0.0
BUFFER/GRINDER/SANDER	0	0.0	0	0.0
PRESS	0	0.0	0	0.0
STATIONARY SAW	0	0.0	0	0.0
MISC MACHINE	1	7.1	3	3.0
VEHICLES	1	7.1	30	30.0
AUTOMOBILE	0	0.0	0	0.0
FORKLIFT	1	7.1	30	30.0
HAND TRUCK/CART/ETC	0	0.0	0	0.0
HEAVY CONSTRUCTN EQUIP	0	0.0	0	0.0
TRUCK/TRACTOR/VAN	0	0.0	0	0.0
MISC VEHICLE	0	0.0	0	0.0
HAND TOOLS	1	7.1	10	10.0
ELECTRIC HAND TOOL (EXCLUDE SAW)	0	0.0	0	0.0
HAMMER/SLEDGE	0	0.0	0	0.0
KNIFE/RAZOR	0	0.0	0	0.0
PNEUMATIC HAND TOOL	0	0.0	0	0.0
PORTABLE HAND SAW	0	0.0	0	0.0

ACCIDENT CAUSE (CONTINUED)	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
ROPE/CHAIN/CABLE	0	0.0	0	0.0
SHOVEL/SPADE	0	0.0	0	0.0
WRENCH - NON-MECH.	0	0.0	0	0.0
MISC HAND TOOL	1	7.1	10	10.0
HOT/FLAMMABLE SUBSTS	0	0.0	0	0.0
FIRE/FLAME	0	0.0	0	0.0
GREASE (HOT)	0	0.0	0	0.0
HOT WATER/STEAM	0	0.0	0	0.0
MOLTEN/HOT METAL	0	0.0	0	0.0
MISC HOT/FLAMMABLE SUBST	0	0.0	0	0.0
DANGEROUS CHEMICALS/DUSTS	11	78.6	356	32.4
ACID/ALKALI	0	0.0	0	0.0
MISC SOAPS/DETERGENTS	0	0.0	0	0.0
EXPLOSIVE/NOXIOUS DUST	0	0.0	0	0.0
PETROLEUM PRODUCTS	0	0.0	0	0.0
MISC CHEMICAL/DUST	11	78.6	356	32.4
MISC CAUSES	0	0.0	0	0.0
INJURY BY ANOTHER	0	0.0	0	0.0
PERSON INJURED	0	0.0	0	0.0
ICE/SNOW	0	0.0	0	0.0
NOT ELSEWHERE CLASSIFIED	0	0.0	0	0.0
NOT STATED	0	0.0	0	0.0
TOTAL	14	100.0	399	28.5

OHIO WORKMAN'S COMP.
CHLORINE & ITS COMPOUNDS
1990 INJURY/ILLNESS STATISTICS

NUMBER OF INJURIES REPORTED	96
NONFATAL LOST DAYS	1025
AVERAGE DAYS LOST PER INJURY	10.7
FATALITIES	0
DISABLING INJURY INVOLVING DISMEMBERMENT DISFIGUREMENT OR LOSS OF USE	0
DISABLING INJURIES OVER 7 DAYS	31
DISABLING INJURIES 7 DAYS OR LESS	65

NATURE OF INJURY	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
AMPUTATIONS	0	0.0	0	0.0
BURNS	28	29.2	102	3.6
CONTUSIONS	0	0.0	0	0.0
DISLOCATIONS	0	0.0	0	0.0
FOREIGN BODY IN EYE	1	1.0	2	2.0
FRACTURES	0	0.0	0	0.0
LACERATIONS/PUNCTURES	0	0.0	0	0.0
SPRAINS/STRAINS	0	0.0	0	0.0
CUMULATIVE TRAUMA DISORDERS	0	0.0	0	0.0
OTHER OCCUPATIONAL ILLNESSES	65	67.7	912	14.0
MULTIPLE INJURIES	0	0.0	0	0.0
NOT ELSEWHERE CLASSIFIED	0	0.0	0	0.0
NOT STATED	2	2.1	9	4.5
TOTAL	96	100.0	1025	10.7
PART OF BODY				
EYES	28	29.2	86	3.1
HEAD	0	0.0	0	0.0
FACE & NECK	1	1.0	1	1.0
BACK	0	0.0	0	0.0
TRUNK/INTERNAL ORGANS	0	0.0	0	0.0
ARMS	2	2.1	5	2.5
HANDS	5	5.2	40	8.0
FINGERS	0	0.0	0	0.0
LEGS	1	1.0	14	14.0
FEET, TOES	1	1.0	10	10.0
MULTIPLE MAJOR BODY PARTS	4	4.2	15	3.8
INTERNAL SYSTEMS	54	56.3	854	15.8
NOT STATED	0	0.0	0	0.0
TOTAL	96	100.0	1025	10.7
TYPE OF ACCIDENT OR EXPOSURE				
CAUGHT IN, ON, OR BETWEEN	0	0.0	0	0.0
CONTACT TEMP EXTR/FIRE/EXPLOSN	0	0.0	0	0.0
CONTACT W/ELEC. CURRENT	0	0.0	0	0.0
FALL: SAME LEVEL	0	0.0	0	0.0
FALL: DIFFERENT LEVEL	0	0.0	0	0.0
CONTACT W/HARMFUL SUBSTANCES	94	97.9	1022	10.9
MOTOR VEHICLE ACCIDENTS	0	0.0	0	0.0
STRIKING AGAINST	0	0.0	0	0.0
STRUCK BY FLY/FALLING OBJECTS	1	1.0	2	2.0
SLIPS (NOT FALLS)/BODILY REACTN	0	0.0	0	0.0
OVEREXERTION	0	0.0	0	0.0
NOT ELSEWHERE CLASSIFIED	0	0.0	0	0.0
NOT STATED	1	1.0	1	1.0
TOTAL	96	100.0	1025	10.7

AGE (CONTINUED)	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
15 AND YOUNGER	0	0.0	0	0.0
16 THRU 19	9	9.4	53	5.9
20 THRU 24	18	18.8	217	12.1
25 THRU 34	31	32.3	147	4.7
35 THRU 44	20	20.8	142	7.1
45 THRU 54	14	14.6	60	4.3
55 THRU 64	2	2.1	20	10.0
65 AND OLDER	1	1.0	365	365.0
NOT STATED	1	1.0	21	21.0
TOTAL	96	100.0	1025	10.7
SEX				
MALES	68	70.8	744	10.9
FEMALES	28	29.2	281	10.0
TOTAL	96	100.0	1025	10.7
ACCIDENT CAUSE				
WORK SURFACES	0	0.0	0	0.0
ELEVATION	0	0.0	0	0.0
FLOOR	0	0 0	0	0.0
LADDER/SCAFFOLD	0	0.0	0	0.0
ROAD	0	0.0	0	0.0
STAIR/STEP	0	0.0	0	0.0
MISC WORK SURFACE	0	0.0	0	0.0
MATERIALS	1	1.0	1	1.0
MINERAL ITEM(BRICK,ETC)	0	0.0	0	0.0
DUST/PARTICLE (IN EYE)	0	0.0	0	0.0
GLASS	0	0.0	0	0.0
LUMBER/WOODWKG MATERIAL	0	0.0	0	0.0
METAL ITEMS/PARTS	0	0.0	0	0.0
TEXTILES	0	0.0	0	0.0
MISC MATERIALS	1	1.0	1	1.0
CONTAINER/FURNTURE/FIXTURE	9	9.4	40	4.4
FURNITURE/FIXTURES	0	0.0	0	0.0
CONTAINER	9	9.4	40	4.4
DOOR/WINDOW/GATE/FENCE	0	0.0	0	0.0
FORM/FRAME/MOLD	0	0.0	0	0.0
RACK/SHELF	0	0.0	0	0.0
SKID/PALLET	0	0.0	0	0.0
MACHINES	4	4.2	15	3.8
CASTING/FORGING/WELDING	0	0.0	0	0.0
CUTTING/SLICING MACHINE	0	0.0	0	0.0
DRILLING/BORING/TURNING	0	0.0	0	0.0
ELEVATOR/CRANE/CONVEYOR	1	1.0	1	1.0
BUFFER/GRINDER/SANDER	0	0.0	0	0.0
PRESS	0	0.0	0	0.0
STATIONARY SAW	0	0.0	0	0.0
MISC MACHINE	3	3.1	14	4.7
VEHICLES	0	0.0	0	0.0
AUTOMOBILE	0	0.0	0	0.0
FORKLIFT	0	0.0	0	0 0
HAND TRUCK/CART/ETC	0	0.0	0	0.0
HEAVY CONSTRUCTN EQUIP	0	0.0	0	0.0
TRUCK/TRACTOR/VAN	0	0.0	0	0.0
MISC VEHICLE	0	0.0	0	0.0
HAND TOOLS	2	2.1	5	2.5
ELECTRIC HAND TOOL (EXCLUDE SAW)	0	0.0	0	0.0
HAMMER/SLEDGE	0	0.0	0	0.0
KNIFE/RAZOR	0	0.0	0	0.0
PNEUMATIC HAND TOOL	0	0.0	0	0.0
PORTABLE HAND SAW	0	0.0	0	0.0

ACCIDENT CAUSE (CONTINUED)	1990 INJURIES	% OF INJURIES	NONFATAL DAYS LOST	AVERAGE DAYS LOST
ROPE/CHAIN/CABLE	0	0.0	0	0.0
SHOVEL/SPADE	0	0.0	0	0.0
WRENCH - NON-MECH.	0	0.0	0	0.0
MISC HAND TOOL	2	2.1	5	2.5
HOT/FLAMMABLE SUBSTS	0	0.0	0	0.0
FIRE/FLAME	0	0.0	0	0.0
GREASE (HOT)	0	0.0	0	0.0
HOT WATER/STEAM	0	0.0	0	0.0
MOLTEN/HOT METAL	0	0.0	0	0.0
MISC HOT/FLAMMABLE SUBST	0	0.0	0	0.0
DANGEROUS CHEMICALS/DUSTS	62	64.6	861	13.9
ACID/ALKALI	0	0.0	0	0.0
MISC SOAPS/DETERGENTS	0	0.0	0	0.0
EXPLOSIVE/NOXIOUS DUST	0	0.0	0	0.0
PETROLEUM PRODUCTS	0	0.0	0	0.0
MISC CHEMICAL/DUST	62	64.6	861	13.9
MISC CAUSES	18	18.8	103	5.7
INJURY BY ANOTHER	1	1.0	8	8.0
PERSON INJURED	0	0.0	0	0.0
ICE/SNOW	0	0.0	0	0.0
NOT ELSEWHERE CLASSIFIED	17	17.7	95	5.6
NOT STATED	0	0.0	0	0.0
TOTAL	96	100.0	1025	10.7

Appendix E

Chemical Characteristics

Solvents

The three chosen chemicals (DCM, MEK, TCE) are classified as solvents. These solvents are organic compounds that can dissolve other materials and are used as cleaners and degreasers (68:123). The typical exposure routes in the workplace are inhalation and dermal contact (skin contact). Solvents are also volatile, meaning they evaporate rapidly into the air and are easily inhaled (68:75). A study performed by the Bureau of Labor and Statistics (BLS) showed that approximately 9% of all chemical burns were caused by dermal contact with solvents (74:9).

Methylene Chloride. Methylene chloride is a colorless halogenated hydrocarbon also known as dichloromethane, methane dichloride, DCM, and methylene dichloride (68:402). The one-half billion pounds of methylene chloride produced in the United States are used for a variety of purposes including fumigation, fire extinguishing, metal degreasing, cleaning, extraction in the food products industry, and paint stripping (59:1). Furthermore, DCM is considered a potential human carcinogen (A2) (61:1348).

Permissible Exposure Limit. OSHA has established a permissible exposure limit (PEL) of 100 ppm (mesured as a volume per volume) averaged over an eight-hour work shift

(54:1). The PEL is based on a Time Weighted Average (TWA). A TWA is the average concentration for a normal 8-hour workday and a 40-hour workweek to which all workers may be exposed repeatedly, day after day, without adverse effects (28:1-2).

Effects of Overexposure. If inhaled, DCM can cause central nervous system damage such as mental confusion, light-headed, nausea, vomiting, and headache (54:1). Continued exposure may cause increased light-headedness, staggering, unconsciousness, and death. High vapor concentrations may also cause eye, skin, and respiratory tract irritation (61:1346). Skin and eye exposure can cause irritation and if trapped against the skin by gloves, shoes, or clothes it can also cause burns (2:1). Dermal contact can also cause dermatitis (54:1). Animal studies indicate that methylene chloride can affect the liver and the kidneys. Because a major metabolite of DCM is carbon monoxide, cardiac arrhythmia is also possible (44:38). Additionally, methylene chloride forms phosgene, a highly toxic fume, on contact with hot surfaces (59:1).

Methyl Ethyl Ketone. Methyl ethyl ketone is colorless and volatile liquid also known as 2-butanone, MEK, ethyl methyl ketone (20:247). MEK is a ketone, a class of chemical that includes acetone, cyclohexanone, and mesityl oxide (58:1). MEK is used as a solvent for dyes, paints, tars, waxes, and in the extraction of lubricating oil (62:1170).

Permissible Exposure Limit. OSHA has set their workplace exposure standard PEL for MEK at 200 ppm in air averaged over an 8-hour work shift, 40-hours a week (53:1). Likewise, ACGIH set a Threshold Limit Value (TLV) of 200 ppm for a normal 8-hour workday and a 40-hour workweek (53:1).

Effects of Overexposure. The related effects of exposure are eye and upper respiratory tract irritation, dizziness, headache, vomiting, numbness (53:2). Long term exposures can cause dryness and irritation to the skin.(53:2). MEK does not effect the liver or the nervous system, but it can amplify other chemicals effects on these systems (1:3).

Trichloroethylene. Trichloroethylene is a colorless, highly volatile, halogenated hydrocarbon also know as acetylene trichloride, ethinyl trichloride, ethylene trichloride, trilene, and TCE (68:414). TCE is used as a solvent, a metal degreaser, a dry cleaning agent, a refrigerant, and as a constituent in many other products such as paints, varnishes, and adhesives (51:1).

Permissible Exposure Limit. OSHA has established a PEL for TCE of 100 ppm in air averaged over an 8-hour work shift, 40-hours a week (3:4). The acceptable ceiling concentration is 200 ppm; and a maximum peak concentration above the acceptable ceiling (maximum duration of 5 minutes in any 2-hour period) is 300 ppm (55:1).

Effects of Overexposure. The related effects of exposure are eye and upper respiratory tract irritation, allergic skin rash (degreaser's flush), dizziness, headache, blurred vision, vomiting, fatigue, possible peripheral nerve disturbances (55:2). Long term exposures can lead to central nervous system depression, dermatitis, and damage to the liver and kidney (68:414).

Bibliography

1. Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile For 2-Butanone.* Oak Ridge National Laboratory: August 1991.

2. Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile For Methylene Chloride.* Oak Ridge National Laboratory: April 1989.

3. Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile For Trichloroethylene.* Oak Ridge National Laboratory: October 1989.

4. Air Force Institute of Technology. *EPA Perspective*, Class handout, ENV 022, Pollution Prevention Management, School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Paterson AFB, OH, July 1991.

5. Aldrich, James. *Pollution Prevention Economics*, Air Force Institute of Technology (AU), Wright-Patterson AFB OH: January 1, 1993.

6. Austin, Teresa. "Superfund: New Leadership, Old Problems," *Civil Engineering*: 46-49 (March 1993).

7. Bailey, Paul E., "Life Cycle Costing And Pollution Prevention," *Federal Facilities Environmental Journal*: 193-203 (Summer 1991).

8. Bishop, Lt Col Edward C. *Bioenvironmental Engineering Role In the Air Force*, HQ USAF/SGPA, Bolling AFB, Class handout, ENV 022, Pollution Prevention Management. School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1991.

9. Bourdeau, Philippe. editor, *Methods for Assessing and Reducing Injury from Chemical Accidents*, John Wiley & Sons, New York: 1989.

10. Bridges, James S, and Emma Lou George. *Pollution Prevention Research Within the Federal Community*, U.S. Environmental Protection Agency (E.P.A.), Cincinnati, OH: Pollution Prevention Research Branch, Risk Reduction Engineering Laboratory: March 1991.

11. Bureau of Workman's Compensation. *Acetone and Other Ketones 1990 Injury/Illness Statistics.* Ohio Bureau of Workman's Compensation, Columbus OH: February 1993

12. Bureau of Workman's Compensation. *Chlorine & its Compounds (Bleach, Tetrachlorophenol, Methyl Chloride, Trichloroethylene, Perchloroethylene) 1990 Injury/Illness Statistics.* Ohio Bureau of Workman's Compensation, Columbus OH: February 1993

13. Bureau of Workman's Compensation. *1990 Occupational Injury and Illness Statistics.* Ohio Bureau of Workman's Compensation, Columbus OH: February 1993

14. Cheney, Richard. *DOD Environmental Leadership and Strategic Plan,* October 10, 1989. Class handout, ENV 022, Pollution Prevention Management. School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1991.

15. Chiras, Daniel D. *Environmental Science,* The Benjamin/Cummings Publishing Company, Inc., New York: 1991.

16. Cohrssen, John J. and Vincent T. Covello. *Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks*, The National Technical Information Service, Springfield, VA: 1989.

17. Code of Federal Regulations, 29 Part 1910.1000, Office of the Federal Register National Archives and Records Administration, Washington: Government Printing Office: July 1, 1990.

18. Dallas, Cham E. and others. "Physiological Pharmacokinetic Modeling of Inhaled Trichlorethylene in Rats", *Toxicology and Applied Pharmacology*: 303-314 (1991).

19. Department of the Air Force. *Pollution Prevention Program - Funding Issues*, Class handout, ENV 022. Pollution Prevention Management, School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1991.

20. Department of Labor. *Industrial Exposure And Control Technologies for OSHA Regulated Hazardous Substances*: Vol. 1, March 1989.

21. EA Engineering, Science, and Technology, Inc., *U.S. Air Force Pollution Prevention Program Manual*, Sparks, Maryland: January 1992.

22. Earth Science Consultants, Inc.. *Pollution Prevention Training and Awareness*, Class handout, ENV 022, Pollution Prevention Management. School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1991.

23. Elves, Dr Robert. ASD/SEH. *Pollution Prevention in Weapon System Acquisition*, Class handout, ENV 022, Pollution Prevention Management. School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1991.

24. Environmental Protection Agency. *Decision Makers Guide to Solid Waste Management*. EPA/530-SW-89-072; Washington D.C.: Government Printing Office, November 1989.

25. Environmental Protection Agency. *Exposure Factors Handbook*, EPA/600/8-89/043; Washington D.C.: Government Printing Office, July 1989.

26. Environmental Protection Agency. *Facility Pollution Prevention Guide*, EPA/600/R-92-088; Columbus, Ohio: Government Printing Office, May 1992.

27. Environmental Protection Agency. *Health Assessment Document for 1,1,1-Trichloroethane (Methyl Chloroform)*. EPA 600/8-32-003F; Washington: Government Printing Office, February 1984.

28. Environmental Protection Agency. *Health Effects Assessment Summary Table (Annual FY91)*, NGIF No. PB91-921100; Washington D.C.: Government Printing Office, January 1991.

29. Environmental Protection Agency. *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual, Part A (Interim Final)*, Office of Solid Waste and Emergency Response, Washington D.C.: July 1989.

30. Environmental Protection Agency. *Recycling Works!* EPA/530-SW-89-014; Washington D.C.: Government Printing Office, January 1989.

31. Environmental Protection Agency. *Reducing Risk: Setting Priorities and Strategies for Environmental Protection*, Washington, D.C.: September, 1990.

32. Environmental Protection Agency. *The Solid Waste Dilemma: An Agenda for Action*. EPA/530-SW-89-019; Washington D.C.: Government Printing Office, February 1989.

33. Environmental Protection Agency. *Waste Minimization Opportunity Assessment Manual*. EPA Manual/625-7-88-003; Washington D.C.: Government Printing Office, July 1988.

34. Environmental Protection Agency. *Waste Minimization Opportunity Assessment: Scott AFB*. EPA/600/S2-91/054; Washington D.C.: Government Printing Office, Dec 1991.

35. Environmental Protection Agency. *Yard Waste Composting: A Study of Eight Programs*. EPA/530-SW-89-038; Washington D.C.: Government Printing Office, April 1989.

36. Freeman, H.F., *Hazardous Waste Minimization - Industrial Overviews*. Pittsburgh, Pennsylvania: Air & Waste Management Association: 1989.

37. Freeman, H.F., *Hazardous Waste Minimization*. New York, New York: McGraw-Hill Publishing Company, 1990.

38. Goldsmith, Lowell A. *Biochemistry and Physiology of the Skin*. New York: Oxford University Press, 1983.

39. Grisham, Joe. *Health Aspects of the Disposal of Waste Chemicals*: Pergamon Press, 1986.

40. House Resolution (H.R.) 5931, *Pollution Prevention Act of 1990*, 101st Congress, 2D Session, Washington: October 25, 1990.

41. Husingh, Donald A. and others. *Proven Profits from Pollution Prevention*. Washington D.C.: Institute for Local Self Reliance, 1986.

42. James, Author and Mary Lord. *Index of Chemical & Physical Data*. New York: Van Nostrand Reinhold, 1992.

43. Lentz, Gideon. "The Diagnosis of Occupational Disease", *Chemical Hazards of the Workplace*. New York: Van Nostrand Reinhold, 26-43 (1991).

44. Levy, Barry S. & David Wegman. *Occupational Health Recognizing and Preventing Work-Related Disease* (2nd Edition). Boston: Little, Brown and Company, 1989.

45. Masters, Gilbert M. *Introduction to Environmental Engineering and Science*, Englewood Cliffs, New Jersey: Prentice Hall, 1991.

46. Mattie, D.R. and others. "Significance of the Dermal Route of Exposure to Risk Assessment," *Conference on the Risk Assessment Paradigm After Ten Years: Policy and Practice Then, Now, and in the Future*. EPA/600/R-93/039; Washington: Government Printing Office, March 1993.

47. McCarthy, BGen Robert. Symposium Briefing to the Engineering and Environmental Management class at the Air Force Institute of Technology. Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1992.

48. McGuire, Robin K. and others. "Analyzing Risk," *Civil Engineering, 61:* 66-70 (December 1991).

49. McPeak, General Merrill A. and Donald B. Rice. *Air Force Pollution Prevention Program*. Memorandum to all Commanders. HQ USAF, Washington D.C: 13 Nov 1991.

50. Meyer, Gary. *OEHL Database for Toxic Chemicals Report*. Occupational and Environmental Health Directorate, Armstrong Laboratory, Brooks AFB, TX: Mar 1993

51. National Institute for Occupational Safety and Health. *Current Intelligence Bulletin 2*. NIOSH, Cincinnati, OH: June 6, 1975.

52. National Institute for Occupational Safety and Health. *Current Intelligence Bulletin 46*. NIOSH, Cincinnati, OH: April 18, 1986.

53. National Institute for Occupational Safety and Health. *Occupational Health Guideline for 2-Butanone*. NIOSH, Cincinnati, OH: September, 1978.

54. National Institute for Occupational Safety and Health. *Occupational Health Guideline for Methylene Chloride*. NIOSH, Cincinnati, OH: September, 1978.

55. National Institute for Occupational Safety and Health. *Occupational Health Guideline for Trichloroethylene*. NIOSH, Cincinnati, OH: September, 1978.

56. National Institute for Occupational Safety and Health. *National Occupational Exposure Survey Report*. Division of Surveillance, Hazard Evaluations and Field Studies, NIOSH, Center for Disease Control, Public Health Service, U.S. Department of Health and Human Services, Cincinnati, OH: 20 May 93.

57. National Institute for Occupational Safety and Health. *NIOSH Recommendations for Occupational Safety and Health, Compendium of Policy Documents and Statements*. DHHS (NIOSH) Publication No. 92-100. Cincinnati, Ohio: GPO, January 1992.

58. National Institute for Occupational Safety and Health. *Recommended Standard for Occupational Exposure To Ketones*. DHEW (NIOSH) Publication No. 78-173. Cincinnati: September 1978.

59. National Institute for Occupational Safety and Health. *Recommended Standard for Occupational Exposure To Methylene Chloride*. 017-033-00194-4; No. 76-138. Washington: Government Printing Office, 1976.

60. National Safety Council (NSC). *Accident Facts 1992 Edition*. NSC, Chicago, IL: Jan 1992

61. Occupational Safety and Health Administration. *Industrial Exposure and Control Technologies for OSHA Regulated Hazardous Substances*. OSHA: March 1989.

62. Parmeggiani, Luigi. *Encyclopedia of Occupational Health and Safety* (3rd ed). Vol. 1, International Labour Office, Geneva: 1980.

63. Rankin, Debra S. & Clare R. Mendelsohn. *Pollution Prevention, an Investment Decision Model To Assess Financial Feasibility For Application To Air Force Processes*, MS thesis, AFIT/GEE/ENV/92S-15, School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1992.

64. Sax, N. Irving & Richard J. Lewis Sr. editors, *Hawley's Condensed Chemical Dictionary*. 11th edition, New York: Van Nostrand Reinhold Company, 1987.

65. Schaefer, H., A. Zesch, and G. Stuttgen. *Skin Permeability*. New York: Springer-Verlag Berlin Heidelberg, 1982.

66. Science Advisory Board: Relative Risk Reduction Strategies Committee. *Reducing Risk: Setting Priorities And Strategies For Environmental Protection*. U.S. E.P.A. Washington D.C.: September 25, 1990.

67. Shelley, Michael L. Class Lecture for ENVR 530, Environmental Risk Analysis. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1992.

68. Sherry, Susan. *High Tech and Toxics: A Guide For Local Communities*. Sacramento, California: Golden Empire Health Planning Center, October 1985.

69. Stein, Jess. editor, *The Random House College Dictionary*. New York: Random House Inc., 1980.

70. Steinberg, Alfred A. and John M. DeSesso. *Are Animal Data Being Used Appropriately to Establish Risks to Humans from Environmental Trichloroethylene and its Major Metabolite, Chloral Hydrate?,"* Unpublished Report, Mclean VA: The MITRE Corporation, 1992.

71. Stevenson, L. Harold & Bruce Wyman. *The Facts on File Dictionary of Environmental Science*. New York: Facts on File, Inc., 1991.

72. The Texas Institute for Advancement of Chemical Technology. *Insights: Safety in the Workplace*. The Texas Institute for Advancement of Chemical Technology, College Station, TX: 1990

73. Tusa, Wayne K. "Reassessing The Risk Assessment," *Civil Engineering,* 46-48 (March 1992).

74. U.S. Department of Labor, Bureau of Labor and Statistics. *Chemical Burn Injuries*. Chicago, IL: October 1989.

75. U.S. Department of Labor, Bureau of Labor and Statistics. *Source of Injury or Illness Report*. Chicago, IL: October 1989.

76. Vest, Gary. Lecture in ENV 022, Pollution Prevention Management. School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1991.

77. Walker, Lt. Col Thomas. Lecture in ENVR 550 symposium, School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, February 1993.

78. Wentz, Charles A. *Hazardous Waste Management*. New York: McGraw Hill, Inc., 1989.

Vita

Captain Michael L. Forcht was born 15 December 1964 in Eugene, Oregon. In 1983, he graduated from Triangle Lake High School in Triangle Lake, Oregon as the class Valedictorian. He attended Oregon State University (OSU) and received a Bachelor of Science Degree in Structural Engineering in 1988. He attended OSU on a Air Force ROTC scholarship and was commissioned in 1988. He was assigned to Lowry AFB, CO as a Civil Engineer in 1988 where he was a civil engineering design officer in charge of the base Military Construction Program (MCP) projects. During this time he personally designed over $2 million in new construction and maintenance projects. In 1990 he was appointed as the Civil Engineering squadron readiness officer, responsible for maintaining the combat capability of 150 personnel. As the readiness officer he performed budget and readiness planning along with organizing the deployment of 112 personnel to Eglin AFB, FL for training. He entered the Engineering and Environmental Management Program, School of Engineering, Air Force Institute of Technology, in May 1992.

Permanent Address: 2166 Grange Hall Rd.
Beavercreek, OH 45431

Vita

Mr. Timothy D. Neu was born on 26 August 1967 in St. Cloud, Minnesota. He graduated from Rocori High School in 1986. In the fall of that year he began college at North Dakota State University in Fargo, North Dakota. He graduated with a Bachelor of Science in Civil Engineering in March 1991. Mr. Neu then began his environmental career as a Palace Acquire Intern stationed at Lowry AFB in Denver, Colorado. At that time he was assigned to the environmental branch and given the responsibility of managing the base asbestos program. In his time there he oversaw many asbestos abatement jobs and a base wide asbestos survey. Mr. Neu also assisted in the oversight of the hazardous waste/hazardous materials program. In May 1992 Mr. Neu was selected to attend the Engineering and Environmental Management masters degree program in the School of Engineering of the Air Force Institute of Technology.

Permanent Address: 1821 N. Lakeman Ave.
Bellbrook, OH 45305

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	26 August 1993	Masters Thesis

4. TITLE AND SUBTITLE
Economic Analysis of Costs Incurred from Chemical Exposures in the Workplace Resulting in Non-Carcinogenic Responses as Additional Justification for Pollution Prevention Projects.

5. FUNDING NUMBERS

6. AUTHOR(S)
Michael Forcht and Timothy Neu

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT/ENV
2950 P Street
Wright-Patterson AFB, OH 45433

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEE/ENV/93S-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFIT/ENV
2950 P Street
Wright-Patterson AFB, OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFIT/GEE/ENV/93S-6

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This research determines the applicability of using costs associated with chemical exposures in the workplace for financial justification of pollution prevention projects. Specifically, this thesis looks at costs incurred due to noncarcinogenic effects caused by chemical exposures. Average costs are determined through researching applicable statistical cost data.

Acute effects are analyzed using an analysis of available statistical accident data from multiple sources. Expected values are then calculated based upon the projected cost of an accident and the probability of having an accident.

Chronic effects are analyzed using an empirical analysis. A risk assessment is used to determine the likelihood of developing a chronic response to workplace exposures measured in terms of a hazard quotient. A probability of developing a response and the cost is then multiplied by the hazard quotient to predict the cost associated with chronic effects due to workplace exposures.

This research shows that for the purposes of financially justifying pollution prevention projects, costs due to acute effects of chemical exposure are insignificant. Further, the cost due to chronic effects cannot be used at this time for pollution prevention justification because necessary workplace exposure data does not exist.

14. SUBJECT TERMS
Pollution Prevention; Chemical Exposures; Non-carcinogenic Responses

15. NUMBER OF PAGES
97

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	None